ALMOST EVERYTHING YOU WANT TO KNOW ABOUT MOON BOUNCE

DIVISION OF VARIAN
301 Industrial Way
San Carlos, California

Moonbounce Notes

During the last year there has been an upsurge of interest in amateur communication via reflection from the moon. All the bands from 50 MHz through 2400 MHz have been involved.

This activity has created more interest in moonbounce and each neophyte "moonbouncer" has had many questions concerning just how to get started:-

-Which band should be used?

-How much power is needed?

-How good should the receiver be?

- What kind of antenna should be used, and how big should it be?

In the process of determining antenna parameters, it is necessary to know how to find and track the moon. In addition, the type of antenna mount, the aiming system and the physical location of the antenna on the available plot of land are a function of the path of the moon.

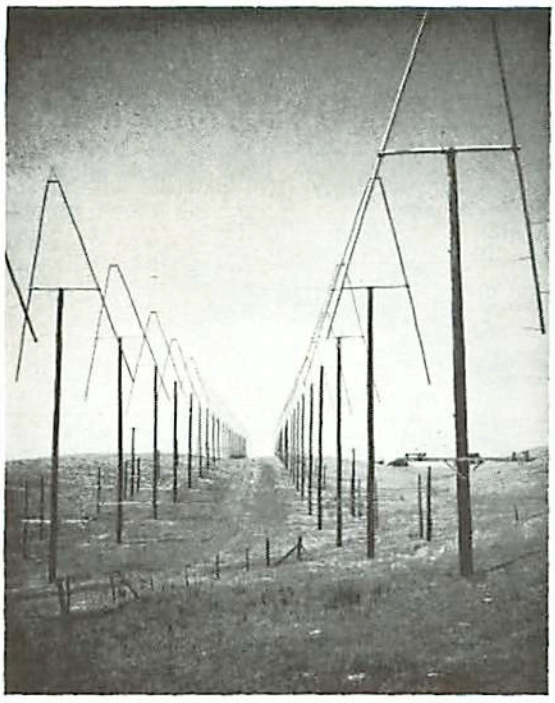
Many articles have been published which will answer these questions and help the beginner and old time "moonbouncer" alike. Much other data are available which have not been published. It is the intent of this compilation of moonbounce notes and articles to reproduce in one place the literature necessary to allow the potential "moonbouncer" to make the basic decisions necessary to start his project.

As time goes on, additional notes will be added.

Contributions from those interested in EME (earth-moon-earth) communication will be gratefully received.

Thanks to the American Radio Relay League for permission to reprint certain articles from QST magazine.

Bob Sutherland, W6PO
EIMAC division of Varian
301 Industrial Way
San Carlos, California
94070



This field full of phased log-periodic antennas was used by the author to obtain reflections from the moon in the 10-meter band. In case you'd like to duplicate the feat, the array is 1200 feet long and 75 feet wide. It has a gain of 27 db.!

The Moonbounce Problem, 28 Mc. and Up

Basic Facts for Determining Equipment and Antennas Needed for Lunar Communication

BY H. T. HOWARD,* W6UGL

THE purpose of this article is to stimulate amateur interest in moonbounce communication, by presenting the basic parts of the problem, such as noise figure, path loss, and antenna gain, in familiar terms. Once these basic factors are understood, they can then be applied to equipment and antenna design for communication via the moon or man-made satellites.

Moonbounce was accomplished on ten meters several months ago at this station with about 1 kw. p.e.p. single sideband, using the array of 48 log periodics shown in the first photograph. The array is 1200 feet long by 75 feet wide, and it has a gain of 27 db., over the range of 20 to 65 Mc.! The beam produced is approximately 1½ degree thick by 30 degrees in azimuth and can be placed to intercept the moon or sun track for about two hours each day. Power is distributed in the array with open-wire line, and tapered sections to maintain the wide bandwidth, and in the usual operation *each antenna* handles from 5 to 10 kilowatts.

* Radioscience Laboratory, Stanford University, Stanford, Calif.

A circuit diagram of the array would look like a corporation organization chart; that is, it starts with one feed line and progressively branches down to the individual antennas which are specially designed and built log periodics, each having a pair of 40-foot booms and a total of 48 elements.

At each power division point there is a movable tap arranged so that the relative phase between antennas is completely adjustable. In practice, the phasing is changed each day to follow the moon's elevation. It takes two men with wrenches and a jeep about two hours to move all of the taps. The array is normally used with a 300-kw. (600-kw. p.e.p.) c.w. transmitter for radar studies of the solar corona and the ionized regions between the earth and the moon.[1]

The selection of ten meters for the moonbounce experiment mentioned above avoids controversy

[1] Research supported by the Electronics Research Directorate of the Air Force Cambridge Research Laboratories, Bedford, Mass., under contracts with Stanford University, Stanford, Calif.

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over the use of large nonprivate antennas for v.h.f. records. Six or possibly fifteen meters might yield similar results if tried. The whole idea, though, is to demonstrate that the absolute minimum antennas for h.f. and lower v.h.f. moonbounce are ridiculously large for individual construction.

Since the array is linearly polarized, Faraday fading is a very important consideration,[2] and the unrecommended expedient of whistling into the microphone was used, until the signal faded up to a usable strength. Then the call was signed in voice and, with the help of some imagination, was received 2½ seconds later. The use of circular polarization will reduce fading, and is certainly required for any serious v.h.f. lunar-communication attempt.

The trick of ten-meter moonbounce points out several facts that will become obvious as you read further. First, station equipment needed for moonbounce on our lower bands is a minimum, and commercially available, but the antenna required is gigantic. Second, cosmic noise and ionospheric effects play a large role below about 100 Mc. With increasing frequency, the antenna becomes physically smaller, but the receiver and transmitter must be the best that amateur ingenuity can produce.

The average loss in decibels for the earth moon–earth path, assuming 500 watts of r.f. power at the antenna terminals and a moon reflectivity of about 7 per cent, is given in Fig. 1. Path loss will vary approximately ± 1 db. during each month as range to the moon changes.[3] Moon reflectivity is currently the subject of several scientific investigations, and while reflectivity appears to be higher at frequencies below 450 Mc., and is perhaps lower above that frequency, the figure given should be accurate enough for a first approach to the problem. If the transmitter power at the antenna terminals is less than 500 watts due to feed-line losses or other practical considerations (such as money) this path-loss number should be increased by the number of db. difference.

The next problem is that of receiver noise figure and sensitivity. Fig. 2 is a plot of cosmic noise *vs.* frequency, presented to give the equipment designer an idea of what is needed for a front end. The *min* and *max* lines show the sky temperatures and minimum usable noise figure that can be expected when the antenna is directed toward the coldest and hottest portions of the sky, respectively. This variation is easily observable even with simple equipment and is a good method of checking antenna and system performance.[4] Fortunately for the communications problem, larger areas of the sky are cold than are hot.

Below about 1000 Mc., cosmic noise is the dominant factor and varies with the portion of the galaxy observed. It can be seen that being cosmic-noise-limited, that is, having the feed-line loss and receiver-noise contribution less than the cosmic noise, at all times, is an engineering feat nearly impossible at 220 Mc. and higher, with the present state of the art.

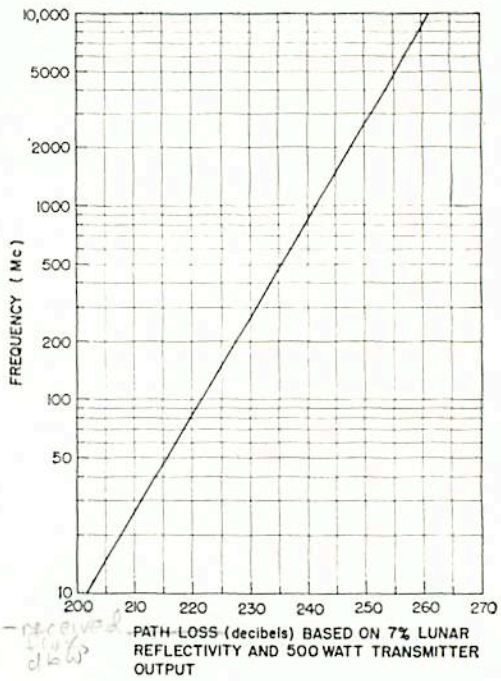


Fig. 1—Moonbounce-path loss *vs.* frequency.

Before going further, it is necessary to clear up some confusion concerning receiver sensitivity and noise figure that has arisen because of improper use of the relation:

Ideal receiver sensitivity = kTB

where

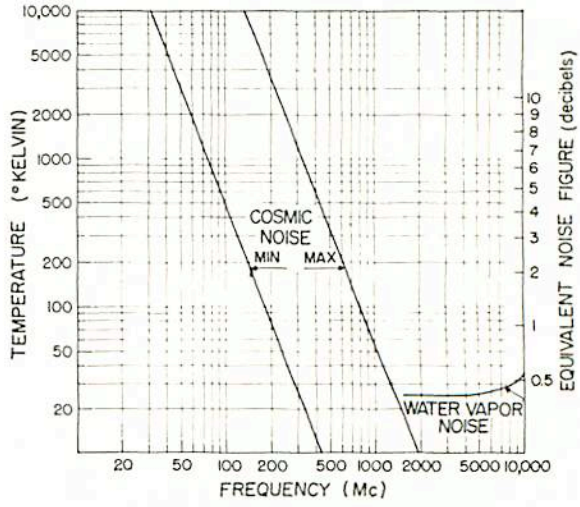


Fig. 2—Cosmic and water-vapor noise limits *vs.* frequency.

[2] Dyce, "The Appearance of the Moon at Radio Frequencies," *QST*, May, 1961.

[3] Pettengill, "Lunar Studies." Lecture notes presented at course on Radar Astronomy, summer session 1961, Massachusetts Institute of Technology, Cambridge, Mass.

[4] Downes, "A Simple Radio Telescope," *Sky and Telescope*, August, 1962.

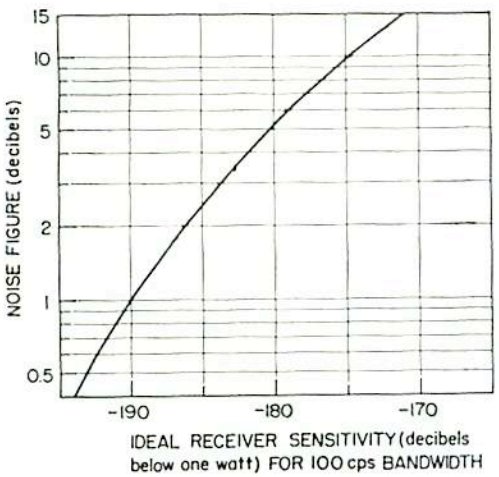


Fig. 3—Ideal receiver sensitivity vs. noise figure.

k is Boltzmann's constant, 1.38×10^{-23} joule/°K

T is temperature in degrees K

B is bandwidth in c.p.s.

If one uses room temperature of 290 degrees K, then it can be shown that:

Ideal receiver sensitivity ($-$dbw.) =

204 db. $-10 \log B -$ db. noise figure.

This relation is correct for systems with noise figures greater than 3 db. (system temperature greater than 290 degrees K), but needs revision to be correct for present-day low-noise amplifiers. By using an equivalent system temperature for T instead of 290 degrees K, we can still satisfy the IRE definition for noise figure and be consistent with present practice. All of this is simply saying that it is possible for a directive antenna and receiver at u.h.f. to look at a portion of the sky that is colder than 290 degrees K.

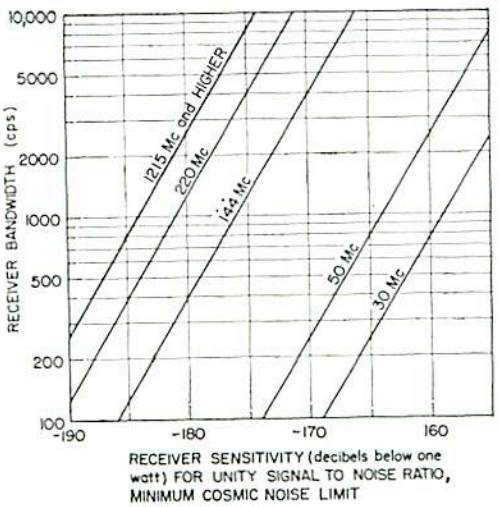


Fig. 4—Receiver sensitivity vs. bandwidth for the various amateur bands.

A plot of the above interpretation for a receiver with a 100-cycle bandwidth is shown in Fig. 3. There are some surprises in this graph that arise from proper use of noise figure. For instance, an improvement in receiver noise figure from 3 db. to 2 db. improves receiver sensitivity not just 1 db., but nearly 3. Going from a 10-db. crystal mixer to a 2-db. paramp yields a sensitivity improvement of 12 db. This makes it pretty obvious that the best possible noise figure and the lowest possible line losses are all important, at frequencies where system noise is greater than cosmic noise.

Fig. 4 uses the information of Fig. 2, and assumes that the system performs to the lower cosmic-noise limit. It shows what receiver sensitivity to expect in each case, for unity signal-to-noise ratio with various bandwidths. If the system is not cosmic noise-limited, the number obtained from Fig. 4 should be decreased by the number of db. difference between the ideal case of Fig. 4 and the actual system. Again, both noise figure and transmission-line loss enter here. The number from Fig. 4, as modified by reality, is the receiver sensitivity in decibels below 1 watt, and can be added algebraically to the path loss of Fig. 1 to obtain the two-way antenna gain necessary.

For example, select 1296 Mc. and assume a parametric-amplifier front end with a 2-db. noise figure [5] and 2 db. of feed-line losses. From Fig. 1 the total path loss is 244 db. and from Fig. 2 the system is definitely not cosmic noise-limited.

Example:

Fig. 1: Total path loss for 500 watts power output	244
Feed-line loss	2
	246 db.
Fig. 4: Cosmic-noise-limited receiver sensitivity (500 c.p.s. bandwidth)	−187 dbw.
Fig. 2: Receiver n.f. = 2 db.	= 170° K
Line loss = 2 db.	= 170° K
	340° K = 3.4 db.
Cosmic noise	= 0.5 db.
Fig. 3: Difference between 0.5 db. cosmic noise and 3.4 db. actual receiver system	+ 10 db.
	− 177 dbw.
	69 db.

$$\frac{69}{2} = 34.5 \text{ db.}$$

This is the antenna gain required at each station for unity signal-to-noise ratio in a 500-c.p.s. bandwidth, but as W1FZJ has pointed out,[6] the ear can be a narrower filter if properly trained.

[5] Troetschel and Heuer, "A Parametric Amplifier for 1296 Mc.," *QST*, January, 1961.

[6] Harris, "The World Above 50 Mc.," *QST*, June, 1961.

(Continued on page 6)

These figures show, among other things, that the initial 1296-Mc. moonbounce, with an 18-foot dish (35 db.) and 300 watts of transmitter power, was both a technical triumph and an operating feat. It is also clear that the higher frequencies are the logical choice for both commercial and amateur work of this type.

As Soifer[7] recently noted, the basic problem is to obtain adequate signal-to-noise ratio, and the graphs presented here should help the equipment- and antenna-oriented amateur get a feel for the moonbounce problem. It should be remembered, however, that marginal systems give marginal results (if any at all), and that these numbers should be used conservatively if reliable communication is the goal. QST

[7] Soifer, "Space Communication and the Amateur" *QST*, November, 1961.

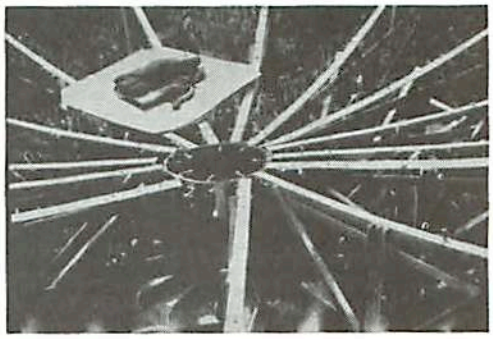
The World Above 50 Mc.

CONDUCTED BY BILL SMITH,* WB4HIP

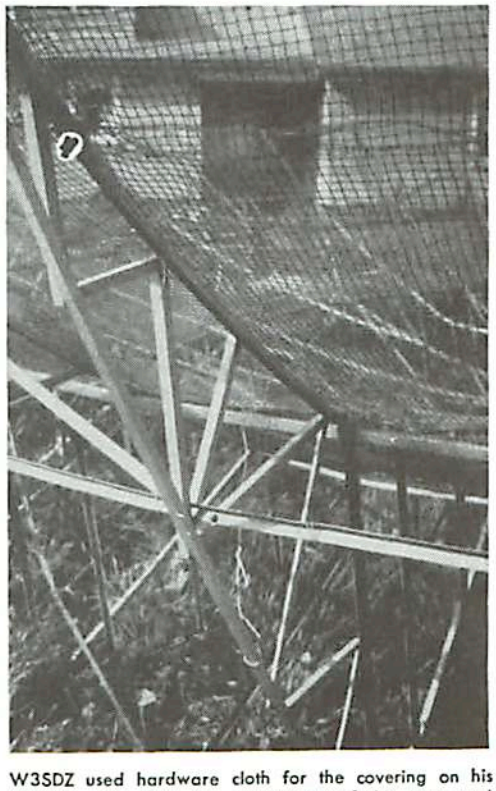
Plain Language E. M. E.

OUR correspondence indicates an ever-increasing interest in amateur space communications. For those turning skyward for new adventure in v.h.f., the possibility of working e.m.e. seems indeed exotic. At my request, Mike Staal, K6MYC, has agreed to offer his guidelines for developing a successful e.m.e. system. These are the result of much work, Mike having traveled both unsuccessful and successful avenues. The discussion is not intended to illustrate a cut-and-dried system that must be used, but rather to point out what equipment is being used, and in some instances, how successfully. We hope this will stir your imagination and interest in e.m.e. communications.

The station at K6MYC is probably as basic and simple as one should consider for e.m.e. To illustrate how little is actually required, the following is *all* that is needed and used at K6MYC. An SBE-34 s.s.b. and c.w. transceiver is used with a receiving converter and transmitting mixer for 144 Mc. The only thing unusual is a common local oscillator tripled to 130 Mc. permitting transceive operation on 144. The transmitting converter is similar to that on page 159 of the ARRL *V.H.F. Handbook*. The receiving converter is an old, much-modified Ameco tube-type with a 6 db. noise figure. A 50-ohm pad is used between the SBE-34 and the transmitting converter to swamp most of the 40 watts of 14 Mc. output. The converter output is 5 watts which drives a *linear* amplifier through a relay. The 5 watts is adequate to drive a pair of 4CX250Rs in the WØMOX configuration (December, 1961, *QST*) to one-kw. input. The amplifier delivers 650 watts which is fed through thirty feet of ½-inch heliax to coaxial switches at the antenna. Two relays are used at the antenna, one for the transmitted signal and the other for double protection of the FET preamp located in the same housing. Belden 8214 carries the preamp output to the receiving converter. A 1-Mc. crystal oscillator running into a tunnel diode provides both calibration at 144.000 and a weak-signal source, which is absolutely necessary for observing receiving-system performance. A noise blanker, 60-cycle audio filter and tape recorder are occasionally used. That is it, aside from the antenna and mount. Compare your station with the aforementioned and you'll probably find



Careful examination of this photo will reveal some construction ideas for the hub of a parabolic reflector. The dish belongs to W3SDZ.



W3SDZ used hardware cloth for the covering on his 432-Mc. dish. Note the construction of the struts and supports.

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very little keeping you from beginning in e.m.e. work except the antenna.

The bare minimum gain required from the 144-Mc. antenna is 20 db. over a dipole. This does not mean that echoes are not possible with slightly less gain, but for any hope of reliability through the moon's cycle, 20 db. is the line when using "normal" receiving systems.

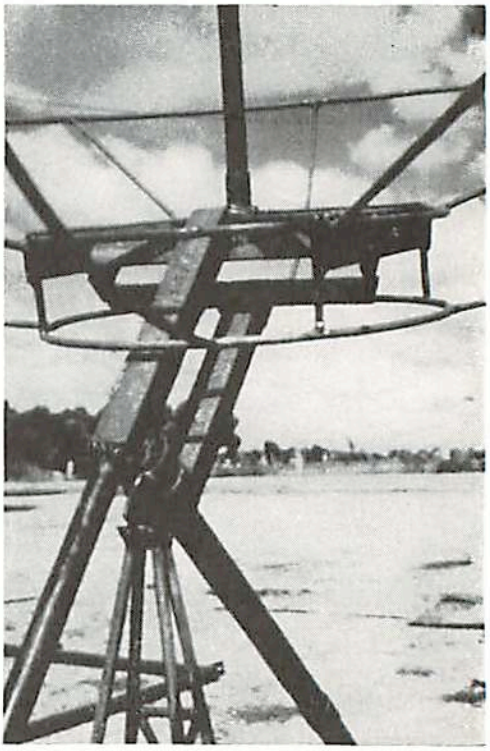
Now about the antenna. To my knowledge, no one has yet been satisfied with the performance of Yagis on an e.m.e. circuit. W6DNG used them but has since changed to an extended expanded collinear which he says is the best of more than 50 e.m.e. antennas he has tried. F8DO has a Yagi array, but doesn't feel it is performing as well as it should. However, short Yagis of 4 or 6 elements may be the answer if you must try them. VE3BZS/VE2 has an array of sixteen, 4-element Yagis and is now doubling that number. He's had some success in hearing his own echoes. K6HCP, using two 26-foot boom Yagis, ran several hours of tests over a period of days with K6MYC with completely negative results. Transmitting at K6HCP and listening at K6MYC produced nothing. The opposite was also tried without success although K6MYC could hear his own echoes.

The antenna at K6MYC is a 160-element collinear which I believe is producing close to the theoretical 24 db. gain. Echoes can be received almost anytime during the moon's 28-day cycle, assuming the Faraday rotation (polarization rotation in the ionosphere) is correct. We will discuss Faraday rotation later as well as the 28-day cycle, which is related to sky temperature (cosmic noise) at various "look" angles. F8DO, VE3BZS/VE2, ZL1TFE, ZL1AZR, WB6DEX, and of course VK3ATN have all heard K6MYC on e.m.e. WB6KAP has an antenna almost identical to K6MYC's and has had equally good results.

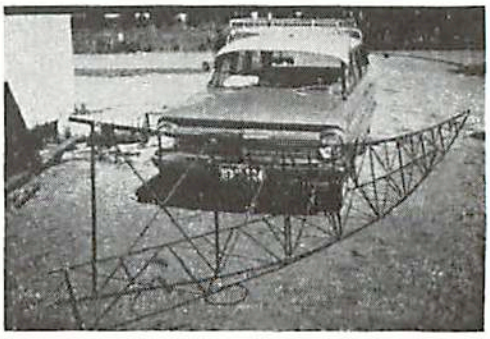
The cubical quad looks good since it fits into the low-*Q* class with collinear types. ZL1TFE heard signals with four 5-element quads patterned after those by W1CER and modified by W7FS. Don't rule out expanded quads as they should be quite practical. Size and weight seems to be their chief drawback.

Rhombics, the king of the h.f. antennas, seem to have a place in v.h.f. circles as well. This antenna does not allow much moon time each month, but the gains achieved can be extremely high, at much less cost than most other arrays. VK3ATN uses four rhombics stacked one above the other with six-foot spacing between for his 2-meter e.m.e. antenna. The antenna is 342 feet long per leg and has an apex angle of about 10 degrees. The gain is calculated at 33 db., over perfect ground, but actual gain is probably closer to 27 to 30 db. VK3ATN has been very successful using this antenna and 150 watts input. The LaPort rhombic is being tried and seems to have possibilities. ZL1AZR has a single-layer one and has copied K6MYC and possibly VK3ATN. More layers or a side-by-side configuration may be in order. The antenna is only 70 feet long. The disadvantages of rhombics are immobility and low elevation angles.

All of the antennas thus far discussed have been linearly polarized. Now let's consider some sort of circularly-polarized antenna. First a definition of circular polarization is in order; let us use the helix to simplify the explanation. Since a helix has no linear element, it theoretically radiates equally in all planes and the wave is launched in the direction of the spiral. Depending on whether the helix is wound clockwise or counterclockwise, the antenna would be called right- or left-hand



Shown is the hub assembly of the VK3ATN dish. The declination and hour angle drive motors are yet to be mounted as is a 16-inch diameter bearing.



This is one of the more than 20 steel tubing trusses being used in the 50-foot dish at VK3ATN. The 20-foot long trusses weigh 30 pounds each and are within ⅛-inch tolerance of a parabolic curve.

circularly-polarized respectively. For point-to point communication using helices, both antenas should be wound the same direction. When listening for one's own echoes, a right-hand signa radiated at the moon will return left-hand. This means that to hear your own echoes the direction of circularity must be switched. Circular polarization can also be achieved with properly phased crossed dipoles orthagonally mounted.

WB6DEX currently uses nine 20-element crossed Yagis, but runs only the horizontal 90 elements when testing with another station using horizontal polarization. Otherwise he would lose about 3 db. by putting half of his power into the vertical elements. However, if both stations used 180 elements circularly-polarized arrays, 3 db. would be gain on both ends — obviously very worthwhile.

Also the problem of long term fading due to Faraday rotation would be eliminated. This polarization mismatch can cost as much as 20 db. when using linear-polarized antennas. Helix antennas have not yet been successfully used for a two-way amateur e.m.e. contact as far as I know, but maybe W8JK's helix will intrigue some of you who need a new challenge. (See W1CER's article on page 20, November, 1965 *QST*.)

Certainly one antenna that should not be overlooked is the parabolic reflector, be it circular or cylindrical. However, dishes of a useful size at 144 Mc. are impractical for the average amateur, but at 432 and higher the picture brightens. (K2UYH described a homebuilt dish in the August, 1966 *CQ*.)

To summarize on antennas, my personal experience tells me circularly-polarized antennas for 432 and above, if at all possible, and below 432 shoot for maximum gain in a low-*Q*, linear polarized array.

Now let's look at a smaller but still important component in the e.m.e. station, the preamp. It may not be entirely necessary if your converter has a noise figure of 3 db. or less, but if located near the antenna the preamp can reduce feedline losses on receiving and possibly lower the system noise figure a bit. The noise figure to aim for at 2 meters is 2 db. You can try for less, but don't expect a noticeable increase in sensitivity, because the lowest sky temperature encountered at 144 Mc. is about 1.9 db. At 432 and above cosmic noise is less and very low-noise devices become more useful. It is doubtful that your system will be cosmic-noise limited. On 144 and 432 transistors appear to be the way to go, and more specifically, FETs or the steadily improving MOS dual-gate FET. Many types and brands are available for under $2. Many good preamp circuits have been published, but most lack protection for the transistor. A pair of diodes, typically 1N100s, back-to-back at the input to ground will save much grief. If you insist on using regular bipolar transistors, be sure to build a good stripline filter to help eliminate overloading of the transistor by strong local stations in the broadcast band and higher. Normally a filter is not needed ahead of a FET.

Little need be said about the balance of the converter except that crossmodulation (overload) of the mixer stage can sometimes be a problem. The use of FETs as mixers is a current solution. Recently RCA began marketing a dual-gate MOS FET pair that look ideal for converters, a 3N140 front end and a 3N141 mixer. Both are under $2 and may be the best yet for 144 and 220.

Next month we'll look at methods used during e.m.e. tests and pass along some time-saving hints. Also a thorough examination of the problems encountered is in order, as is a discussion of antenna mounts and drive mechanisms. In the meantime, you should read W6UGL's article, "The Moonbounce Problem, 28 Mc. and up," on page 20, September, 1963, *QST*.

A Layman's Look at E.m.e.—Part II

K6MYC continues his discussion this month of propagation problems effecting e.m.e. communications and what the amateur can do to alleviate some of them.

Although there are electrons everywhere in our atmosphere and beyond, those in the ionosphere have the greatest effect on v.h.f. and u.h.f. signals leaving this planet. This cloud of elecrons is in a constant state of flux, their number either increasing or decreasing, or moving about to form clouds or blobs, much the same as vapor clouds. For our discussion, however, think of the ionosphere as a homogeneous layer with no irregularities. A plane-polarized 2-meter signal entering this layer is gradually rotated and may go through several rotations before passing through the ionosphere and into space. If electron content is high, as it normally would be during daylight hours, the signal may rotate many more times than it would during early morning hours. This phenomenon is known as *Faraday rotation*.

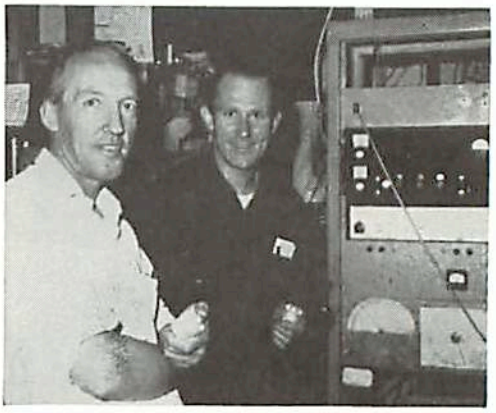
Regardless of the plane of polarization originally, the wave may come through the layer in any plane until it strikes the moon. As an example, consider the direction of rotation to be clockwise. When the signal strikes the moon and is reflected, it maintains its plane of polarization until beginning to re-enter the ionosphere, where again it begins to rotate, still in a clockwise direction, until returning to the antenna from which it was transmitted. An originally horizontal signal may have rotated six times plus 45 degrees leaving the ionosphere, and another six times plus 45 degrees upon re-entry, adding up to a net 90-degree rotation change, or vertical polarization. The signal received on a horizontal antenna may suffer a 20- to 30-db. loss from polarization shift alone.

The problem of Faraday rotation is further complicated when contact with another station is attempted. The transmitted signal must pass through two probably-different ionospheric sections before arriving at the other antenna. The polarization of the arriving signal may match the plane of one of the two antennas, but not necessarily both, or either. To put it simply, your own echoes may be coming back well, but the other station may not hear anything. But if transmissions are continued for an hour or so, chances are your own echoes will fade and the other station may start hearing you.

(A demonstration of this occurred on Dec. 20, when K6MYC and VK3ATN had another e.m.e. QSO. During the entire QSO, 1302 to 1310 GMT, neither was able to hear his own echoes. VK3ATN also heard W6YK for 8 minutes following. — EDITOR)

Another interesting fact about Faraday rotation is the relation to the hemispheres involved. A plane-polarized signal leaving the northern hemisphere twisting clockwise will return in the southern hemisphere counter-clockwise. It is possible that the effects of Faraday rotation can be nullified if the electron content of the ionosphere were the same for both paths. The shift related to hemispheres does not occur if both stations are in the same hemisphere. Schedule times should be chosen when both stations can use approximately the same antenna elevation angle (the moon the same distance above the horizon at both station) as there are usually two to three times as many electrons in the horizon path to the moon as in the path at a 45-degree elevation angle. The best time for ionospheric stability is between 2200 and 0600 local time at both stations.

Another factor entering into echo quality is *scintillation*, which cannot be corrected with circular polarization. An uneveness of electron density forms in the ionosphere and acts on a signal much like a lens on light. These "blobs" can have a focusing or defocusing affect on a signal producing unrealistically strong echoes, or no echoes at all. Scintillation, from my observations, is more apparent at frequencies below 144 Mc.



New Zealand, e.m.e. buff Ralph Carter, ZL1TFE, (left) recently visited K6MYC in Saratoga, California. Ralph is actively working towards e.m.e. contacts on 144 and 432 from his home in New Zealand.

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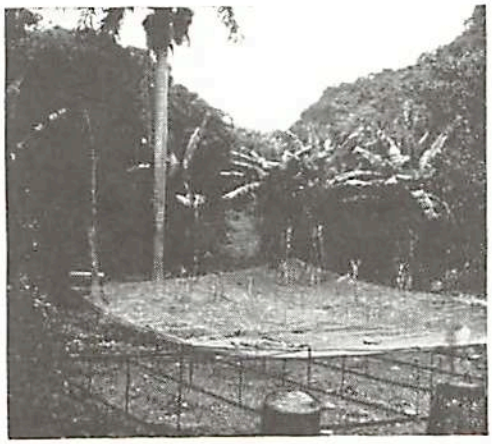
Libration fading caused by the rocking motion of the moon also effects echoes. For short periods the path loss can be reduced by as much as 6 to 10 db. The moon is a rough surface and acts like many reflectors. Sometimes they add up in phase, while on the average they give a seven per cent πr^2 reflectivity. Libration spread is more troublesome at frequencies higher than 144 Mc.

Another factor having a large bearing on whether or not contacts can be made with marginal systems is *cosmic noise*. On 432 and above this should not cause much concern, but at 144 it is a different story. The minimum cosmic noise at 144 Mc. is about 1.9 db., which is quite easily heard with modern transistors. Cosmic noise is greatest is the direction of the Milky Way, or the galactic center. From my experience cosmic noise can make a 2-db. receiving system perform like a 6-db. system, or worse, when the moon is near the galactic center. There is usually a period of five to seven days each month when the moon is at its lowest declination angles. These days should be avoided if success depends upon



W1FZJ/KP4 is building this 50 foot square "dish" for 432-Mc. e.m.e. tests. The dish will later be expanded to 150 feet for use on 144. A movable feed will be mounted atop a 60-foot tower in the center of the dish

optimum receiving capabilities. Even the period as the moon is increasing its declination to its peak of approximately 27 degrees is not especially quiet. In my opinion the ten-day period after the moon has reached its declination peak is the best.

The following suggestions are offered as possible solutions to the problems just discussed:

1) Faraday rotation can be handled with circular polarization, or in part by carefully planned schedule times.

2) Larger than minimum antennas help overcome scintilation, libration fading and cosmic-noise effects.

3) An effective method of reporting and confirming signal reports helps in completing information exchanges. Avoid using code characters requiring dots, such as the letters I, E, S and H, and the numbers 2 through 7. The following system is currently being used by those scheduling VK3ATN:

T — signals detected
M — letters or portions of calls copied
O — Both calls and report copied
MT — nearly solid copy
5 — solid copy, no need for code

By this system an O plus both calls received at both ends and confirmed with RRR establishes a contact. Had this sytem been in use for my November 22nd test with VK3ATN we probably would have made another contact. However, by the old system VK3ATN was sending 3s represented by the letter E. Es are easily lost to fading and are sometimes not discernible from noise pips ringing in narrow-bandwidth audio filters. Especially after many hours of listening for weak signals, dashes are much easier to detect.

4) Receiving system modifications such as post detection, phase lock, noise blanking and cancellation all can help find signals in the noise. F.s.k. should offer a 3 db. signal-to-noise improvement and is an area for experimentation.

5) Keep transmitting and receiving periods short. I prefer 1 to 2-minute periods, particularly in daylight hours when Faraday rotation is rapid; 90 degrees every 15 to 30 minutes. Echoes can appear, peak and fade in 5 minutes or less. Five-minute periods are used by many, since some detection schemes require 3 to 5-w.p.m. c.w. speed for proper integration time.

6) Use relatively slow-speed c.w., under 10 w.p.m. When testing with VK3ATN my transmission periods are two minutes long. During the first minute each call is sent 2 or 3 times, and the report is sent the second.

7) Be sure of your frequencies, times and calling sequences. Frequencies must be within one kilocycle.

8) Keep your antenna as close as possible on the moon. If your antenna has a 5-degree beamwidth at the 3 db. points, you probably can't afford to be 5 degrees off. It is worthless to build a good antenna system and then waste it with poor

Willis Brown, W3HB, Bethesda, Maryland, recently hosted Andy Kalt, DL8PK, Wahn, West Germany (center), and Bill Smith, W3GKP, of early moonbounce fame. DL8PK is active on 2 meters in Germany. By the way, Massachusetts meteor jockey W1JSM is the son of W3HB.

aiming. This has been the principal cause of many e.m.e. failures.

9) Don't start listening for echoes in a narrow bandwidth (under 500 cycles) unless you are experienced or have a receiving system that requires it. I prefer an 800 to 1000-cycle bandwidth but most of my receiving is done in a 2.1-kc. bandwidth, with the ear providing the "selectivity."

10) When searching for weak echoes, continuously sweep the 500 to 1000-cycle portion of the band where the signal should be. I've found I can detect signals this way that might otherwise be lost in the noise. The ear can detect pitch changes easier than a steady note.

11) Doppler shift on two meters is not much of a problem. I've never heard an echo shift more than 500 cycles at 144 Mc. If the moon is rising, the signal will appear high in frequency. As the moon passes due south there will be little or no shift; then as the moon begins to set, the echo will appear lower in frequency. When listening for your echo from a rising moon, set the receiver so the transmitted signal produces a 200 to 300-cycle note. The echo will then produce a 500 to 700-cycle note. The opposite is true of a setting moon. Doppler on 432 and higher is of more concern and will produce a 1-kc. shift or more, except when the moon is due south of your antenna.

Next month's concluding discussion of this series will cover antenna mounts, drives and readout systems.

E.M.E. for the Layman — Conclusion

This month we conclude a three-part discussion of e.m.e. (earth-moon-earth) principles by Mike Staal, K6MYC. The final section covers antenna mounts, drive systems and readout mechanisms.

First the prospective moonbouncer must decide if he is going to use his antenna system for anything other than e.m.e. experiments. This decision governs the selection of an appropriate mount and drive system. A very simple mount can be constructed if the antenna is to be used only for e.m.e. and thus be aimed at a specific point in space. This may be a logical place to begin, but you will probably soon become frustrated at being limited to perhaps 5 or 6 hours each month when the moon passes through the antenna's pattern. I suggest at least a partially-steerable array.

If only e.m.e. is contemplated, a polar (or equatorial) mount would be a wise selection as it requires only one drive mechanism for tracking and some form of manually tilting the array slightly from day to day to set the *declination*[1]. To accomplish this, your antenna mast or tower must be mounted parallel to the axis of the earth. Thus, if your station location is at 35° north, the mast would be fixed at an angle of 35° from the earth's surface at such location, oriented in a north-south direction (see fig. 1.). The declination (manually-tilted axis) changes from day to day. Information may be found in *The American Ephemeris and Nautical Almanac*, 1968, available through the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. for a nominal price. All that is necessary now is that your drive mechanism rotate the antenna at a rate of 15° per hour to track the moon.

This is all fine and dandy for e.m.e., but if you want to use your array for satellites, meteor scatter, aurora or something similar, a polar mount is not much good. A drive system permitting the array to be fully steerable in both azimuth and elevation (az-el) is the answer.

The array at K6MYC is mounted atop a homemade 12½-foot tower. The four legs of the tower are fastened to a platform which in turn is bolted to the roof of the garage directly above the operating position. A large unmodified prop pitch motor is mounted inside the top of the tower. A husky steel plate is welded to the rotating gear and another plate is attached to the first with ordinary door hinges, see the photographs. These hinges are employed in the elevating mechanism. To this plate a 3-inch aluminum channel is attached and the main boom of the array is clamped in this channel. A jack screw with right-hand left-hand square threads starting from the center out raises and lowers the array. At the lower end of the jack screw is a 20-to-1 gear reduction box giving a zero to 90° elevation time of three minutes. With the plates together the array is pointing straight up. The entire elevation drive rotates with the array.

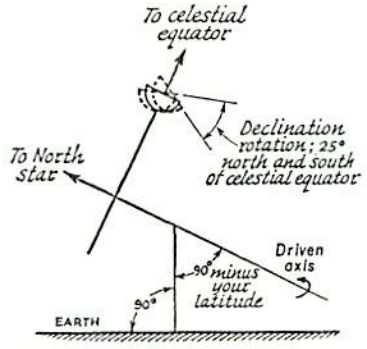


Fig. 1.

Selsyn hookups are used for direction readout and may be varied to suit the particular builder. I'll let you work out your own azimuth system, but my elevation selsyn mount is quite simple. The selsyn is attached to the main array boom and aligned with it. A weight was tightly affixed to the selsyn shaft and, of course, the weight always hangs straight down regardless of the position of the array. The mates to both selsyns are mounted on a panel in the shack. Crude, perhaps, but it gives *one-degree accuracy*, and in e.m.e. you can't afford less!

A handy item for telling if your array is pointing at the moon is the RCA SQ2520 photo-cell costing about $2, or its equivalent. This device is sensitive enough to detect the light of even a small sliver of moon. When placed at the end of a 20-inch long one-inch diameter tube and the leads connected to an ohm meter, it is an

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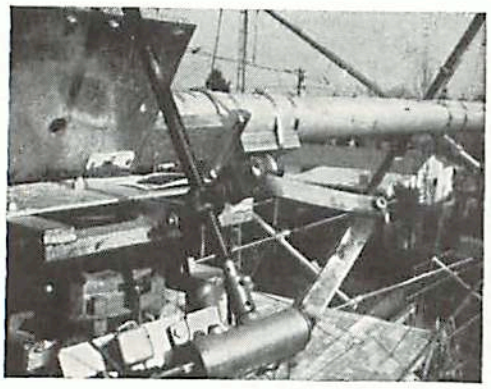
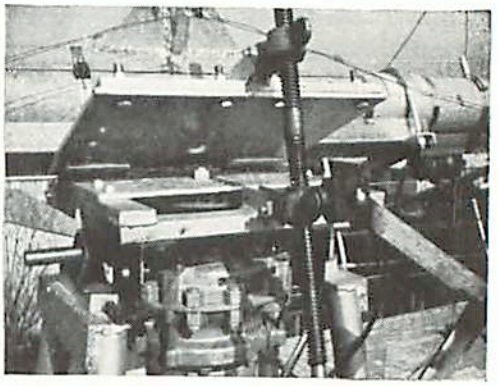


Mounted on the lower end of the jack screw is the 20-to-1 reduction system. Note the collinear elements and main boom.



The elevation selsyn is mounted on the boom to the right of the mount. Note the jack screw, elevation plates and channeling holding the main boom on the mount assembly.

accurate indicator of proper aiming. Obviously it must be mounted so to be aimed along the exact plane of your array. It is useful only at night when the moon is visible.

As can be seen, the problems of mounting, steering and controlling an e.m.e. array are mostly mechanical and must be left to the ingenuity of the builder. Following the basic principles given here on locating the moon the builder may develop his own system.

It has been a pleasure to present these notes on e.m.e. problems, and it is my hope that many of you will become interested in building your own e.m.e. system. — *K6MYC*

The World Above 50 Mc.

CONDUCTED BY BILL SMITH,* K4AYO

Beginning Moonbounce—101

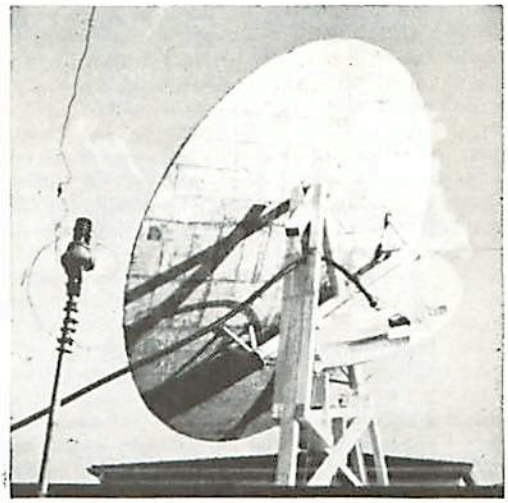
EACH month we receive letters from prospective moonbouncers inquiring for reference material, and hints how to begin their e.m.e. project. In this column for January, February and March 1968 appeared a three-part series by K6MYC, designed especially to answer the most common questions. For those who do not have these issues, we'll paraphrase some of the highlights this month, but suggest you obtain the originals from a friend, or ARRL Headquarters at the nominal fee of 75 cents each.

Basically, this is what is required: 500 watts or more of transmitter output, the best possible receiver front end, a bigger antenna than most of us will ever erect, the means of aiming the array at the moon, and much perseverance. All, but the latter, may be store-bought, if you're so inclined.

Lets look at each. The transmitter power is easily acquired at 144 MHz., the most popular e.m.e. band, 220 MHz., where apparently there is no active e.m.e. work, and at 432 MHz. 1296 and up are progressively more difficult. There are numerous transistors capable of achieving the necessary noise figure at 144, many in the one dollar price range. The picture doesn't change too much at 432; at 1296 the device will cost 10 dollars or more.

The antenna, its type, size and aiming, may be considered together. Success has been had with collinears, Yagis, rhombics and dishes, or parabolic reflectors. The most popular, because it is tolerant of less-than-optimum amateur construction techniques, is the collinear. K6MYC designed, and later discussed in the April, 1967 edition of this column, a modification of a commercially available collinear. The modified version of that antenna is now on sale. At 2 meters, it is probably the best available commercial antenna.

Both SM7BAE and ZL1AZR, who together hold the world's 144-MHz. e.m.e. record, use multiple-Yagi arrays. Another promising 2-meter Yagi array was described by Oliver Swan at the recent West Coast V.H.F. Conference. In tests at K6MYC, a four-bay array of these Yagis, spaced 80 inches both horizontal and vertical, recovered the same amount of e.m.e. signal from KØMQS as did a 40-element collinear array. Physically the collinear array is about three times as large as the Yagi array. Details of this antenna will appear soon in *QST*.



Mounted on the roof of his Los Angeles home, this is the homemade dish of WB6IOM. He used this dish to successfully work G3LTF and establish a new 1296-MHz. moonbounce record. The 16-foot diameter dish consumed 450 square feet of sheet aluminum and 70 pounds of epoxy to bond the aluminum sheets. (WB6IOM photo)

Rhombics, used with much success by VK3ATN and KØMQS, are capable of developing gain in excess of 30 db. over isotropic. Their disadvantages are physical size (several hundred feet in length) and fixed direction, except in the case of VK3ATN who varied the direction a few degrees by a pully and track arrangement. Rhombics are not feasible at the average city amateur location.

The parabolic reflector, more commonly known as a "dish," is essentially a low-efficiency antenna, something in the order of 35 percent. In addition, because of its physical size, especially at 144 and 432, it is not practical for the backyard e.m.e. enthusiast. However, at 1296 and higher, good gain can be developed from a modest size dish. A picture of WB6IOM's 16-foot dish, used in establishing the world's e.m.e. distance record on 1296, appears elsewhere in this column.

Even more important is how you aim the array. It matters not how much gain the array has if it can not be aimed at the moon. Three systems are available; fixed position, partially steerable (polar mount), and fully steerable. A fixed-position array is the simplest to build. You have only to determine the place in space where the moon will travel through the array's pattern at a given time, and fix the array in that

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position. This method, however, limits the time each month the moon will pass through the antenna's pattern, and who you can work because of matching the "window." The window is a mutual place in space where antennas at both stations are pointed at the moon simultaneously.

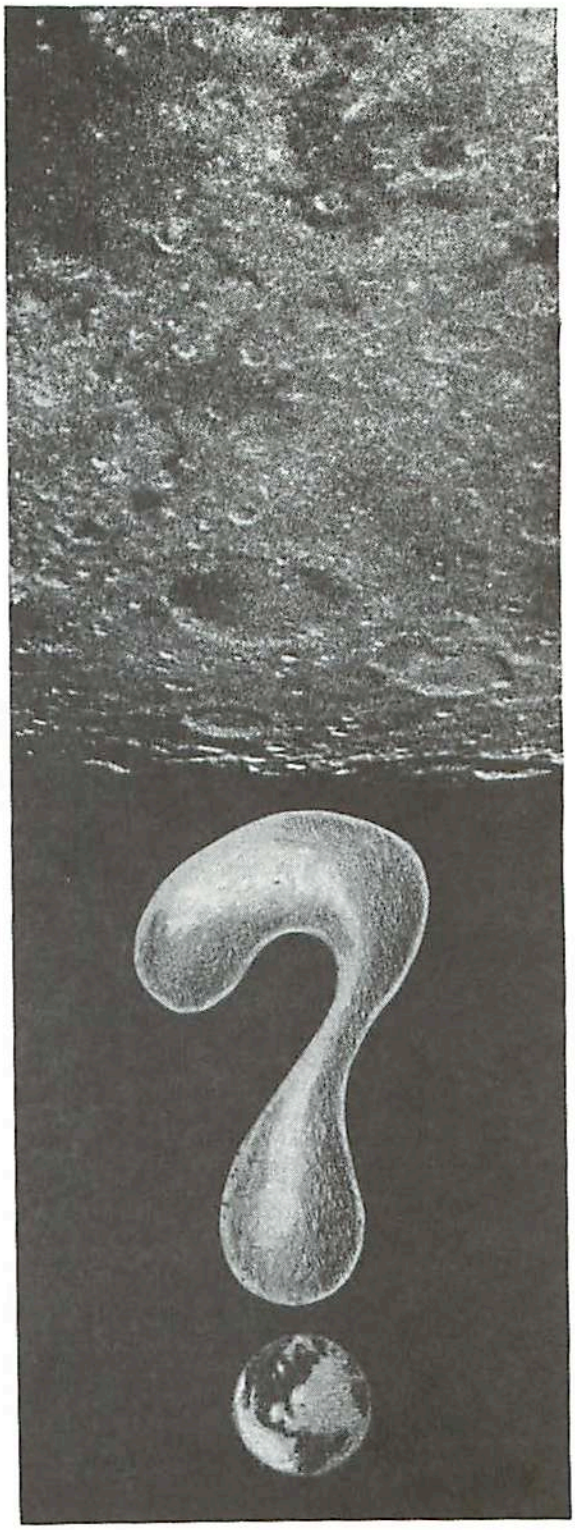
The partially steerable, or polar mount, antenna is especially suitable for e.m.e. work. It needs to be set only once daily for declination (the angle in degrees north or south of the celestial Equator, or elevation angle) and then rotated in azimuth (horizontal plane) to track the moon. The moon travels across the sky at approximately 15 degrees per hour.

A fully steerable array, in both azimuth and elevation (az-el mount), is more flexible for use on other propagation modes, but is difficult mechanically to construct and calibrate for e.m.e. purposes. This is the most desirable type for satellite work.

All right, we've thrown out some facts; what do they boil down to? For the e.m.e. neophyte I'd suggest the following, and you e.m.e. greybeards may sit back and stroke them. Try 144 MHz., there is more activity, and technically 2 meters is more easily achievable. Construct a collinear array of at least 160 elements. That puts you into the 20-db. gain e.m.e. ballpark. Mount the array in a fixed position, taking into consideration who you wish to schedule. The mount may be modified at a later date to a polar configuration, after you become more familiar with e.m.e. techniques.

Much of this discussion may be directly applied to satellite programs, hopefully to soon again grace the amateur horizon through the Amsat and Nastar projects. E.m.e. and satellite work is within the grasp of many of us. As KØMQS recently said, "if I can work e.m.e., anyone can." What Dick said is true — *if* you have the perseverance to put the system together, and stay with it until it works. You still can't buy that!

—...—



How High the Moon

BY DON LUND,* WAØIQN

Reprinted from July, 1965 QST

THE YEAR 1964 will long be remembered by v.h.f. moonbounce enthusiasts. First, the patient work of Bill Conkel, W6DNG, and Lenna Suominen, OH1NL, paid off with the first two-meter moonbounce contact, and then KP4BPZ really showed the possibilities of such work. Postmortems on the week end of June 13 and 14 were held wherever v.h.f. men gathered, but one aspect of our participation seems clear. Many groups and individuals depended upon their ability to visually align their antennas on the moon. Cloudy weather meant failure: partly cloudy weather meant disastrous breaks in tracking the moon.

Getting around this trouble is really pretty easy. First, you need to know where your antenna is pointed. If you're using good rotators, the indicators tell you. If you're using an "Armstrong" system, attaching "setting circles," which are circular dials with 360-degree markings, will tell you. Now the only thing you need to know is where in the heck the moon is!

The purpose of this article is to show two ways of calculating where the moon will be in the sky at a given time on a given date. The first way is quick and dirty. With no mathematics and no references other than this article, it will predict the moon's position to an accuracy of 5 degrees or so for observers within the United States. Since an antenna with an honest 20-db. gain will have a half-power beam width of about 13 degrees, 5-degree accuracy should be acceptable for most applications. If this isn't good enough, a second way is described. It is both accurate and tedious. To use it, one needs a table of trigonometric functions and one reference book. Either of these methods will help you aim your antenna at the moon in fair weather or foul.

All of this discussion will be in terms of elevation and azimuth coordinates. Elevation is the height in degrees of the center of the moon above the horizon. Azimuth is the bearing of the moon, measured clockwise from North. For example, the elevation of the horizon is 0 degrees, and the elevation of a point directly overhead is 90 degrees. The azimuth of the eastern horizon is 90 degrees, while the azimuth of the southern horizon is 180, and so on. We are going to stick to "az-el" coordinates because this is the simplest type of mounting for an amateur to build and align. Also, because of the moon's rapid motion in declination (declination is the same, in celestial coordinates, as latitude in geographical coordinates), other types of mountings do not offer the advantage for the moon that they do for heavenly bodies with fixed declinations.

The Moon's Position; Quick Way

If we watch the moon's path across the sky for a month or so, we see that it shows a cyclic variation. The moon might, on the first night, rise quite high in the sky. The next night it would not rise quite as high, and the next night it would be even lower. After about 13 days it would be lowest in the sky, and the next night it would be

* 430 S. 45th St., Boulder, Colorado.

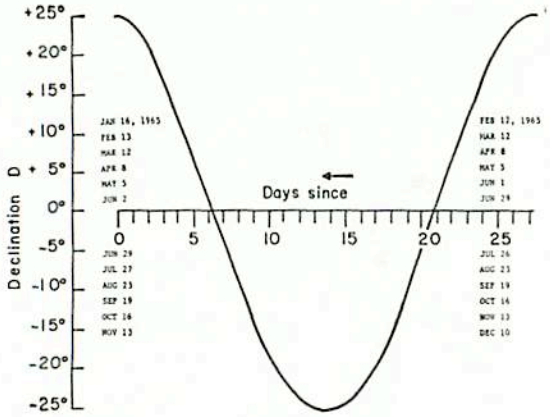


Fig. 1—The average declination of the moon during 1965.

higher again, until after about 27 days, it would be at its highest again. This is because the moon wobbles in declination. The wobble is almost sinusoidal, with a period of about 27 days, as shown in Fig. 1. The dates given are the starting dates for the oscillation. Since the period isn't exactly 27 days, it is necessary to slip a day every so often, as on September 18–19. The maximum amplitude changes about 1½ degrees during 1965, so the curve shows the mean declination, D, during 1965. Thus on July 26, 1965, the moon's declination is + 25 degrees. On August 2, seven days later, the declination is 0, while on August 3, D = − 4 degrees.

Knowing the moon's declination, we may compute its path across the sky (see Fig. 2). We see that when the moon's declination is most positive, it passes highest in the sky; when the declination is most negative, it is lowest in the sky. At some time, call it T, the moon is due South. At $T - 1$, that is one hour before T, the moon is on a solid line corresponding to the declination from Fig. 1, where it crosses the dashed line marked "$T - 1$." An hour and a half later, the moon is still on the same solid line, and is where the dashed line marked "$T + 1/2$" crosses it. At $T - 1$ and $T + 1/2$, we can read the moon's azimuth and elevation off the bottom and side scales. One word of caution about Fig. 2: It has been computed for an observer whose latitude is 40 degrees North, which is on a line passing through San Francisco, Indianapolis and Philadelphia. For observers north and south of this line, the elevation scale is squeezed or stretched. However, for the kind of accuracy we need, the curves will produce acceptable results over most of the continental United States, except Texas, Florida and Maine.

All that is needed now is to find the time, T, at which the moon is due South. This is shown in Fig. 3. Again, the dates are the starting times of the periods, which are about 29 days long. The time can then be read directly in local standard time. For example, the moon is due South at midnight on July 12, 1965. On August 3, 22 days later, the moon should be due South at about 4:40 P.M. local standard time. As before, Fig. 3 represents an average curve for 1965, computed for an observer at the middle of the United States. East and West Coast times may be off by several minutes.

In summary, the complete procedure is:

a) Given the date, find D from Fig. 1.

b) Given the date, find T from Fig. 3.

c) Knowing D and T, enter Fig. 2, reading off azimuths and elevations at hourly intervals before and after T. For illustration, let's say we want the azimuth and elevation of the moon on August 3, 1965. From Fig. 1, $D = -4$ degrees, and from Fig. 3, $T = 4{:}40$ P.M. In Fig. 2, the $D = -4$ degrees curve must lie a sixth of the way down from $D = 0$ degrees to $D = -25$ degrees. Pencilling a curve like that in, at $T - 3$, that is at 1:40 P.M., the azimuth is 127 degrees and elevation is 29 degrees. At 2:40 P.M., the azimuth is 141 degrees, and elevation 32 degrees. Following along, we can find elevation and azimuth every hour. Sounds a little complicated at first, but with some practice, it becomes quick and easy.

The Moon's Position: Exact Way

For the man who has everything — a 300-foot dish and an IBM computer — the easy way may be neither satisfying nor accurate enough. For the man with such excellent capabilities, we offer a cookbook which shows one way of computing the moon's elevation and azimuth. We won't define things like hour-angle, for these definitions would constitute a full course in astronomy. Rather, we will just tell you how to compute, and let you study the references if you wish.

The first step is to compute the local sidereal time, which we call T_s. Pick a Greenwich Mean Time, T_g, for which we want to compute the moon's position in the sky. At this point we must refer to *The American Ephemeris and Nautical Almanac, 1965* (or whatever year you wish) which is available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. Copies are often available at nearby observatories, and occasionally at nearby universities. In the *Ephemeris*, under the section

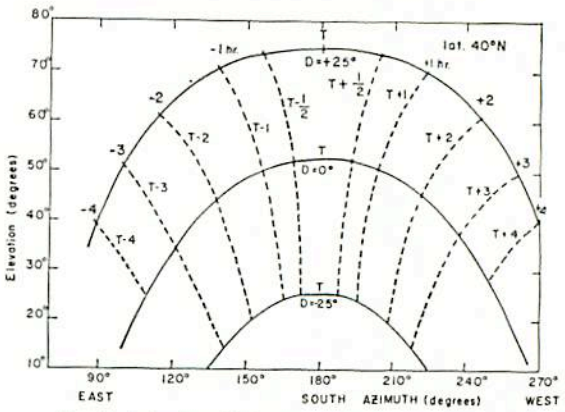


Fig. 2—Azimuth and elevation of the moon.

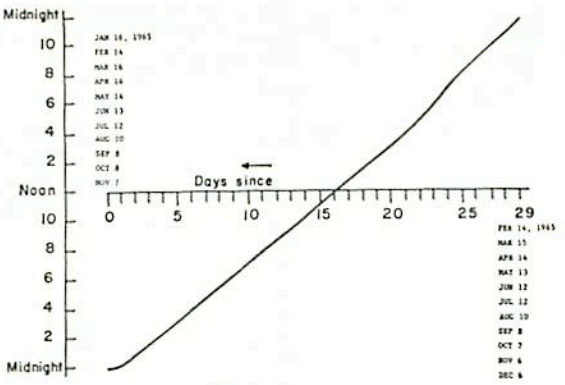


Fig. 3—The average local standard time at which the moon appears due south.

titled "Universal and Sidereal Times, 1965" there is a column called "Sidereal Time, Hour Angle of the First Point of Aries — Apparent." One entry is given for each day of the year. Look up the value for the date you wish, and call the value T_s. Then the local sidereal time may be computed from

$$T_s = 1.002778T_g + T_s - 24\frac{l_1}{360}$$

where l_1 is your longitude in degrees, west of Greenwich. Next, compute the hour angle of the moon; call it *h.a.m.* To do this, in the *Ephemeris*, in a section titled "Moon, 1965, For Each Hour of Ephemeris Time," for each date there is a column showing "Apparent Right Ascension" for each hour of time. Look up the Apparent Right Ascension for the date and time of interest; call it *r.a.m.* Then the hour angle of the moon, in degrees is:

$$h.a.m. = (T_s - r.a.m.)\frac{360}{24}$$

Next, we compute the elevation of the moon; call this angle E. This is computed from

$$\sin E = (\sin D \times \sin l_2) + (\cos D \times \cos l_2 \times \cos h.a.m.)$$

where l_2 is the latitude of the observer and D is obtained from the column "Apparent Declination" which is just to the right of the "Apparent Right Ascension" column in the *Ephemeris*. Having found E from the tables of trigonometric functions, look up cos E. Then the azimuth, A, can be computed from:

$$\cos A = \frac{\sin D - \sin l_2 \times \sin E}{\cos E \times \cos l_2} \text{ and}$$

$$\sin A = \frac{\cos D \times \sin h.a.m.}{\cos E}$$

From the trigonometric tables, we can then look up A.

For the person who needs this accuracy, and has access to an IBM computer, a Fortran program for the above may be obtained by writing the author.

Summary

To permit aiming antennas at the moon through cloudy skies, we have shown two ways of computing the position of the moon in the sky. The first way is as simple as we know how to make it. Its accuracy is poor by astronomical standards, but should be sufficient for most amateur applications. The second way is more accurate, but involves tedious computations. We comment that we have ignored certain fine points in the second method, such as the difference between Ephemeris and Greenwich Mean Time and the fact that the Ephemeris values of right ascension and declination are as seen from the center of the earth. Such refinements can be introduced if the need for ultimate accuracy arises.

References

For a general reference which provides an excellent introduction to the terms and ideas used here, we would recommend *Astronomy*, by R. H. Baker (D. Van Nostrand Co., Inc., 1960). For more detailed information, which includes the derivation of expressions like those which we have used in the Exact Method, we could recommend *Elementary Mathematical Astronomy*, by C. W. C. Barlow and G. H. Bryan, as revised by H. S. Jones (University Tutorial Press, Ltd., 1961). Tables in Figs. 1, 2 and 3 were supplied by the High Altitude Observatory, Boulder, Colorado. QST

POLAR MOUNTS FOR MOON TRACKING

Technical Editor, *QST*:

"How High the Moon?" in July 1965 *QST* was an excellent article on el-az antenna aiming, but there is one statement that gives me concern: "Az-el is the simplest type of mounting for an amateur to build and align. Also, because of the moon's rapid motion in declination, other types of mountings do not offer the advantage for the moon. . . ."

In my article (January 1965 *QST*), a discussion of designing and building a polar mount for moon tracking was discussed. While certainly condensed, it was complete enough for the serious amateur to get started on design work.

So let's compare mount methods. First of all, two movements are required for either type of mount, and they are made essentially the same way. The only real difference in a polar mount is that its axis is inclined to point at the North Star (northern latitudes). So there is practically no difference in the construction materials or work required to construct a polar mount.

The mention of alignment, I assume, means calibration of the mount. Here is where you can begin to appreciate the polar mount. Large high-gain antennas with sharp patterns don't always point electrically where you think they do by bore-sighting methods. Nature has provided us with the sun to find out where the antenna is pointing electrically. (If you can't hear sun noise, you don't have enough gain to work moonbounce, except possibly KP4BPZ.)

The *Nautical Almanac* (which is cheaper than the *Ephemeris & Nautical Almanac* mentioned in "How High the Moon?") has a simple hourly table which tells you in astronomical coordinates exactly where the antenna is pointing, once you have found the sun with the antenna. You simply calibrate your readouts to these figures. Now any time you want to find the moon, a check of the table will give you the exact settings for your mount.

If automatic tracking is desired, a simple clock-controlled drive on the hour-angle axis will keep your antenna on the moon from horizon to horizon. A change in the declination is required once a day, as the moon only moves about 2 degrees per day in declination.

In contrast, an el-az mount requires that two corrections, for both elevation and azimuth, must be constantly fed to the antenna. The corrections must be made manually, as no simple way is available to make an el-az mount auto-track, short of an IBM computer. — *Victor A. Michael, W3SDZ, Box 345, Milton, Penna.*

Reprinted from September, 1965 QST

Tracking the Moon—In Simple English

Practical Ideas for Designing and Aligning a Polar Mount

BY VICTOR A. MICHAEL,* W3SDZ

A MAJOR pitfall facing the prospective moonbouncer is the antenna mount and tracking system. Even a 50-foot dish is of no value in lunar communication, if it cannot be pointed at the moon and kept there. When we began our moonbounce efforts, many hours were spent pouring over astronomy texts. It was determined rather quickly that a whole new language would have to be learned for a proper understanding of the moon-tracking problem. Gathered together here are some of the essentials involved.

Earth-Space Relationship

Understanding the earth-moon relationship in space is the first step in solving the moon-tracking problem. This relationship is best illustrated with a polar mount, as in Fig. 1. A polar mount is simply an elevation-azimuth mount with its azimuth axis parallel to the axis of the earth. Thus a polar mount at the equator would have its axis parallel to the earth (horizontal, to the viewer on the ground), while at the North Pole the axis would be vertical, or at a 90-degree angle to the plane of the earth. Your latitude determines the position of the polar axis with respect to the earth's surface, as illustrated in Fig. 1. Once this is determined, we can proceed to a few other terms.

Celestial Equator. An extension of the earth's equator; the circle that would be formed at a right angle around the polar axis.

Meridian. The north-south line directly overhead.

Hour Angle. The angle in degrees to the right of the meridian. (Degrees can also be transferred into time: 15 degrees equals 1 hour; 1 degree equals 4 minutes.)

Declination. Angle in degrees north or south of the celestial equator.

Using the Nautical Almanac

This is the most important tool you will use in setting up, calibrating, and using your moonbounce antenna. It is available from the U. S. Government Printing Office for $2.00. Be sure you get the right book; there is a similar publication from the same source titled *The American Ephemeris and Empirical Nautical Almanac.* This is more expensive, and harder to use for amateur applications.

On page 39 is a portion of the tables found in the *Nautical Almanac.* It will be noted that the position of the moon is plotted for each hour of GMT. As an example, at 1200 GMT Jan. 1, 1965, the GHA (Greenwich Hour Angle) is 15 degrees 16.5 minutes. This means that the moon has passed overhead at Greenwich, and is now 15 degrees 16.5 minutes, or just over one hour, to the right of the meridian, as the observer faces south. The declination is given as S 23 degrees 39.5 minutes, which means that the moon is at this position south of the celestial equator.

Once you know where the moon is at Greenwich, a simple formula may be applied to determine its position with respect to your own location. The declination is always the same, no matter where you live. The only factor that changes is the hour angle. The Local Hour Angle (LHA) can be obtained by the formula

$$\text{LHA} = \text{GHA} \begin{matrix} - \text{ west} \\ \\ + \text{ east} \end{matrix} \text{ longitude.}$$

Getting back to our example, suppose you l've at 75 degrees west longitude. We find that the moon would have an LHA of 300 degrees 16.5 minutes, or approximately 4 hours before meridian.

Mount Design Considerations

After you examine your almanac you will discover a few facts about the moon's habits that will help you to design a mount. First of all, the moon spends about two weeks above the celestial equator and about two weeks below. The maximum declination is about 25 degrees

* Box 345, Milton, Pa.

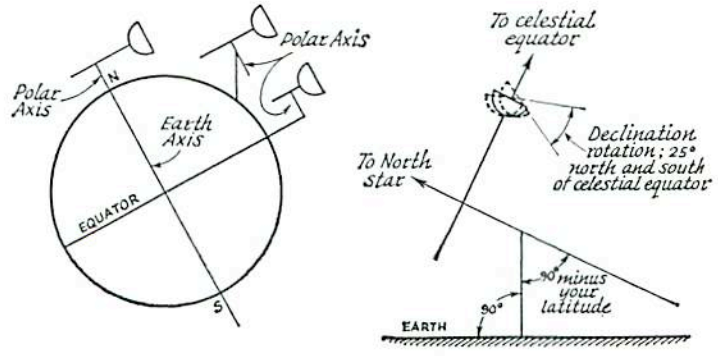


Fig. 1—Principles of the polar mount for moon tracking. At the left it can be seen that the polar axis is always parallel to the axis of the earth. Its position with respect to the earth's surface depends on the latitude of the observer. Two planes of rotation are required; the declination, which may be varied a small amount from day to day as required; and hour-angle, which should be controlled with a clock drive to follow the moon.

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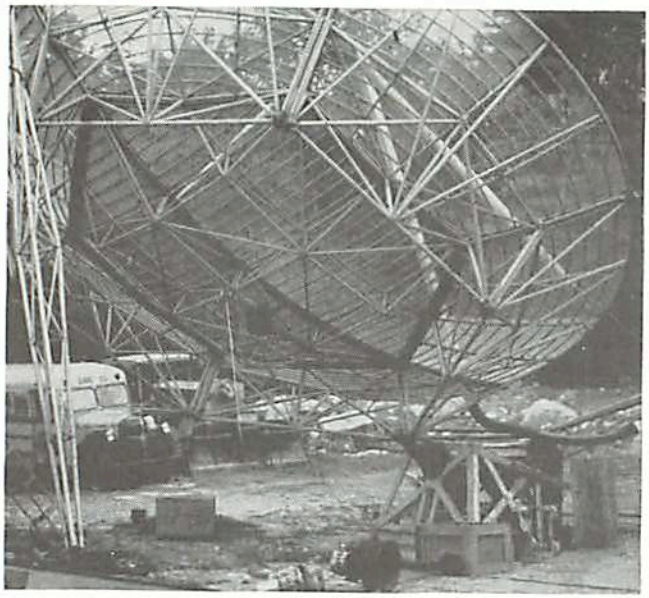

Fig. 2—Simplified polar mount and 28-foot dish at W1BU. Principles of the mount and its clock drive are explained in the text.

north or south of the celestial equator. Tracking ability for about 3 to 5 hours of hour angle each side of local meridian should be satisfactory.

At this point it is possible to make some compromises in order to simplify the mount in favor of a larger antenna. For instance, at W1BU, Sam gave up two weeks out of a lunar month in order to use the 28-foot dish of Fig. 2 in recent moonbounce tests. He can elevate the antenna above, but not below, the celestial equator. The high edge (upper left in the picture) is elevated to the desired position, while the lower edge rests on the pedestal at the lower right. The hour angle is controlled by a clock drive, just visible at the lower center. Though complex enough, this is far simpler than the true polar mounts used on the 18-foot dish at W1BU, or the mount and drive for the 256-element collinear array at W3SDZ, Fig. 3.

Calibration of the Mount

Obviously, if you are going to use the information in the *Nautical Almanac* with your mount, there must be some system of readout. There are

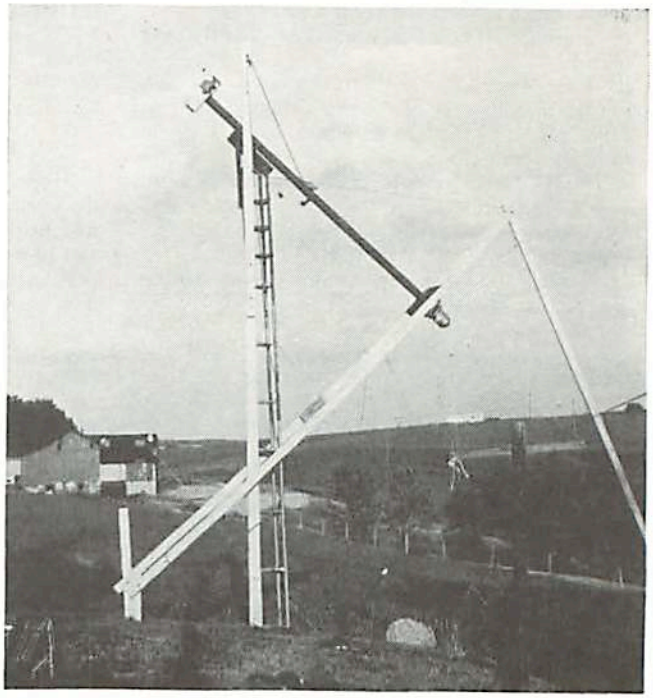

Fig. 3—Polar mount at W3SDZ, before the 256-element 432-Mc. collinear array was in place. The complete array is pictured in November 1964 QST, page 75.

many possibilities, and many different systems will evolve. As a starting point, a few ideas will be discussed here, and then "to each his own."

As a practical matter, the declination need be set no more than once per day, for it changes less than 2 degrees in 24 hours. For a few hours of moonbouncing effort each day, less than 1-degree variation is involved. Unless your antenna pattern is much sharper than the best amateur efforts to date on frequencies below 1300 Mc., this error is no problem. Declination readout can be rather simple: a calibrated scale on the antenna mount, a selsyn readout, or even a good 10-turn pot geared to the declination axis, and connected to a mercury battery and a meter. Anything accurate to plus-or-minus 1 degree should be all right.

Hour-angle readout and automatic tracking are the chief problems in moon tracking. The moon appears to move across the sky at slightly less than 15 degrees per hour. Actually, it is the earth that is moving at 15 degrees per hour. The moon is also moving, but at less than 1 degree per hour. Thus our basic problem is to drive the polar or hour-angle axis at 15 degrees per hour with a clock. The simple procedure of turning off the hour-angle drive for about 3 minutes once each hour, until the moon catches up, keeps things more than accurate enough for antenna tracking.

Now a "clock" doesn't necessarily have to look like a clock. For instance, a large synchronous 60-cycle motor driving a gear train at 1 revolution per day, coupled directly to the hour-angle axis, will work. The W1BU system is shown schematically in Fig. 4. Actual readout can be by any method that will develop plus-or-minus 1-degree accuracy.

When the mount is made, the antenna mounted, and the readout devices reading, the next question will be where is the antenna *really* pointing? This may sound simple, but most would-be moonbouncers have had trouble with this problem. Fortunately, nature has provided us an almost constant radio signal that permits a rather accurate calibration of the antenna system to be made. That signal comes from the sun. It will be seen that the almanac gives identical information on GHA and declination for the sun: thus, by listening to solar noise you can calibrate your polar mount in the same terms of reference as you will use in moon tracking. Some time spent reading K2LMG's "Antenna Patterns from the Sun," *QST* for July, 1960, will be well spent at this point.

What you have just read covers some of the essentials. It is hoped that enough information has been given to enable the prospective moonbounce enthusiast to determine his requirements for mounting and tracking. If any serious experimenter in this field needs help at this point, the author will be glad to try to be of assistance. QST

G.M.T.	SUN			MOON				
	G.H.A.		Dec.	G.H.A.	v	Dec.	d	H.P.
d h	° ′		° ′	° ′	′	° ′	′	′
1 00	179 09·2		S23 02·3	201 09·9	11·7	S22 48·3	4·9	54·0
01	194 08·9		02·1	215 40·6	11·7	22 53·2	4·7	54·0
02	209 08·6		01·9	230 11·3	11·7	22 57·9	4·7	54·0
03	224 08·3	••	01·7	244 42·0	11·6	23 02·6	4·5	54·0
04	239 08·0		01·5	259 12·6	11·6	23 07·1	4·4	54·0
05	254 07·7		01·3	273 43·2	11·5	23 11·5	4·4	54·0
06	269 07·4		S23 01·1	288 13·7	11·6	S23 15·9	4·2	54·0
07	284 07·1		00·9	302 44·3	11·5	23 20·1	4·1	54·0
08	299 06·8		00·7	317 14·8	11·4	23 24·2	4·0	54·0
F 09	314 06·5	••	00·5	331 45·2	11·5	23 28·2	3·8	54·0
R 10	329 06·2		00·3	346 15·7	11·4	23 32·0	3·8	54·0
I 11	344 05·9		23 00·1	0 46·1	11·4	23 35·8	3·7	54·0
D 12	359 05·6		S22 59·9	15 16·5	11·3	S23 39·5	3·6	54·0
A 13	14 05·3		59·7	29 46·8	11·4	23 43·0	3·5	54·0
Y 14	29 05·0		59·5	44 17·2	11·3	23 46·5	3·3	54·0
15	44 04·8	••	59·3	58 47·5	11·3	23 49·8	3·2	54·0
16	59 04·5		59·1	73 17·8	11·2	23 53·0	3·1	54·0
17	74 04·2		58·8	87 48·0	11·3	23 56·1	3·0	54·0
18	89 03·9		S22 58·6	102 18·3	11·2	S23 59·1	2·9	54·0
19	104 03·6		58·4	116 48·5	11·2	24 02·0	2·7	54·0
20	119 03·3		58·2	131 18·7	11·2	24 04·7	2·7	54·0
21	134 03·0	••	58·0	145 48·9	11·1	24 07·4	2·5	54·0
22	149 02·7		57·8	160 19·0	11·2	24 09·9	2·5	54·0
23	164 02·4		57·6	174 49·2	11·1	24 12·4	2·3	54·0

Table I—Section of a page from the *Nautical Almanac*, showing solar and lunar data for each hour of January 1, 1965, at Greenwich.

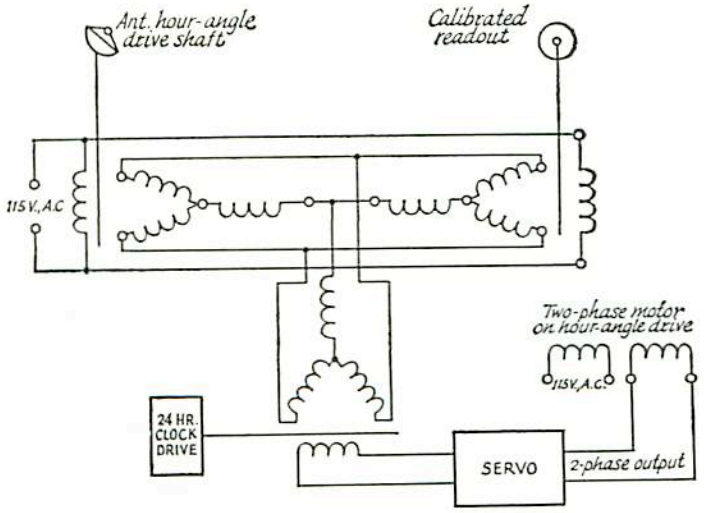

Fig. 4—Schematic diagram of the clock drive and readout system at W1BU.

USING SUN NOISE

BY DON LUND,* WAØIQN

ONE may hear the question "How many db's of sun noise do you get?" asked among serious v.h.f. men. Checking system performance of an advanced v.h.f. station by measuring the amount of noise received from the sun can be most useful, but there are some pitfalls that must be avoided. Our aim here is to set out the relationship between the power radiated by the sun, the antenna characteristics, and the receiver performance. If we know any two of these sets of parameters, we can measure the third. Finally, we'll explore some of the pitfalls inherent in talking about "db's of sun noise."

Solar Temperature, Antennas and Receivers

Twenty years or so ago, astrophysicists were arguing over whether the outer atmosphere of the sun was hotter than the visible surface. Radio astronomy provided some of the evidence that the outer atmosphere was much hotter than most astrophysicists had previously imagined. The result was that the "apparent temperature" of the sun increased with wavelength, at all wavelengths longer than a centimeter or so. (Apparent temperature comes in because the size of the sun is different at different wavelengths. So the sun is taken to be the same size as the optical sun, and apparent temperature is the temperature it would have, to radiate the measured power, at given wavelength, from this size of disc.)

What happens if we point an antenna at the sun? If the beamwidth of the antenna is just exactly the size of the sun, the antenna temperature will be the same as the temperature of the sun at this wavelength. Antenna temperature doesn't mean that we could burn a finger on the antenna; it means that the antenna is delivering the same amount of power to the transmission line that would be delivered by a resistor heated to the antenna temperature. This means that if we took a 50-ohm resistor, and heated it to 400,000°K, it would generate the same amount of noise at 432 Mc. as would be delivered to a 50-ohm resistor by an antenna with a ½-degree beamwidth pointed at the sun.

Antennas used by hams are not that sharp. If an antenna with a 10-degree beamwidth were pointed at the sun, its gain would be less, and it would deliver less power to the transmission line than a ½-degree antenna. Said differently, the antenna temperature would be lower for the broader antenna. In equation form

$$T_a = T_s \frac{\Omega_s}{\Omega_a}$$

where T_a is the antenna temperature, T_s the apparent temperature of the sun, Ω_s is the solid angle subtended by the visual sun (7×10^{-5} steradians), and Ω_a is the solid angle corresponding to the half-power beamwidths of the antenna[1]. If θ_H and θ_V are the half-angles to half-power beamwidths in the horizontal and vertical planes in degrees, then

$$\Omega_a = \frac{\pi}{4} \frac{\theta_H}{57.3} \frac{\theta_V}{57.3}, \text{ approximately.}$$

For illustration, an antenna which was 15° to the −3 db. points in the horizontal plane and 10° in the vertical plane would "see" a solid angle

$$\Omega_a = \frac{\pi}{4}\left(\frac{7.5}{57.3}\right)\left(\frac{5.0}{57.3}\right) = 8.99 \times 10^{-3} \text{ steradians}$$

The antenna is connected to a feed line which has some loss. If we call the feed line loss, when expressed as a ratio, A, we have

$$T_b = A\ T_s \frac{\Omega_s}{\Omega_a} + (1 - A)\ T_o$$

for T_b, the temperature at the receiver terminals due to the power received from the sun. T_o is the earth's temperature, usually taken as 290°K.

With no signal input, the receiver temperature is

$$T_R = (N - 1)\ T_o$$

where N is the noise factor of the receiver (noise factor is related to noise figure in the following way: if we express noise figure as a ratio, and add 1, we have the noise factor. A 6-db. noise figure corresponds to a noise factor of 5.).

If the sun noise at the output of the receiver is d decibels above the receiver noise, and if we converted to a ratio, call it D, then $d = 10 \log_{10} D$, and combining all the above, we have:

$$A\ T_s \frac{\Omega_s}{\Omega_a} + (1 - A)\ T_o = D\ (N - 1)\ T_o$$

The answer to "how many db.'s of sun noise" then is

$$D = \frac{1}{N - 1}\left[A \frac{T_s}{T_o} \frac{\Omega_s}{\Omega_a} + (1 - A)\right]$$

An equation much like this has appeared here before[2]; perhaps this presentation, which shows where such an equation comes from, will help in understanding what will be said later.

Let's work an example, showing how practical results may be predicted. If the receiver has a noise figure of 5 db., then $N = 4.16$. If the feed-line loss is 2 db., then $A = 0.631$, and if we are interested in 432 Mc. the apparent solar temperature is about 500,000°K for a condition when the sunspot number is 50 (see below). T_o is 290°K

* P.O. Box 1664, Boulder, Colorado 80301.

[1] For further discussion, see Pawsey and Bracewell, *Radio Astronomy*, Oxford University Press, Oxford, England, 1955, p. 21. Steradian: The solid angle subtended at the center of a sphere by a portion of the surface whose area is equal to the square of the radius of the sphere.

[2] See Bray and Kirchner, "Antenna Patterns from the Sun," *QST*, July 1960.

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(about room temperature) and $\Omega_s = 7 \times 10^{-5}$. If the antenna beamwidth is 10° by 10° to the half-power points, its half-beamwidth to half-power points is 5° by 5°, and $\Omega_a = 6.0 \times 10^{-3}$. Then

$$D = \frac{1}{4.16 - 1}\left[0.631\,\frac{5 \times 10^5}{2.9 \times 10^2}\,\frac{7 \times 10^{-5}}{6.0 \times 10^{-3}} + (1 - 0.631)\right] = 4.14$$

Converting this back to decibels, the sun noise should be almost 6.2 db. above the receiver noise for this system. There is one problem with this calculation: The sun radiates noise of both vertical and horizontal polarization (usually equal amounts) while most antennas accept only one polarization. If this is the case, the antenna only accepts half the incident radiation, and we must subtract 3 db. for polarization loss. In such a case, the sun noise would be 3.2 db. above receiver noise.

Making Measurements

The radio astronomer would measure N, A, and the antenna parameters, and then knowing these would measure T_s daily by measuring daily values of D. As hams, we are probably more interested in measuring the antenna parameters, or in monitoring our receiving system to make sure everything is working the way it should. This way leads to some trouble, simply because we don't know enough about T_s. At frequencies below about 1000 Mc., the apparent solar temperature isn't very well known for several reasons. The first is that not too many solar observatories have measured solar temperatures daily over a long period of time in this frequency range. While Potsdam, Ottawa, and Toyokawa, among others, measure daily solar temperatures between 1,000 and 10,000 Mc., and have over most of a sunspot cycle by now, not very many protracted measurements are available for the frequencies we are talking about. The second reason is that the solar temperature varies from day to day. Radiation at these frequencies comes from high in the solar atmosphere, and there is still much to be learned about this region of the sun. Therefore, solar temperatures often show little correlation with sunspot number, which is really a measure of activity in the lower part of the sun's atmosphere. The best guess that can be made as to solar temperature as a function of frequency, and the amount it increases for a Wolf Sunspot Number of 100, is shown in Table 1.

TABLE 1

Frequency	*Temperature (Sunspot No. = 0)*	*Percentage Increase (Sunspot No. = 100)*
144 Mc.	1,100,000°K	10%
220	1,100,000	12%
432	400,000	50
1296	150,000	100

These values have been obtained by comparing the reported results of Allen[3] with the daily values reported by the Toyokawa Observatory of the Research Institute for Atmospherics of Nagoya University. The accuracy of these values is not very good.

With this caution in mind, some good information can be obtained from monitoring solar temperature. One thing that can be done is to find, experimentally, what the beamwidth of an antenna is. If D turns out to be more than 2 (that is, 3 db. above receiver noise), we can find the half-power beamwidth ($2\theta_H$ and $2\theta_V$) by pointing the antenna at a point in the sky that the sun will cross, and letting the sun slowly drift through the antenna pattern. When the sun is in the center of the antenna pattern, put a 3-db. attenuator *between the antenna and transmission line* (not between the converter and i.f. strip). Such an attenuator is easily made from coaxial cable (about 29 feet of RG-58/U for 432 Mc.). Clock the times at which the receiver output from sun alone is the same as with the sun at the center of beam and the 3-db. attenuator in line. Since the sun drifts one degree every four minutes, dividing the minutes (between calibrated −3 db. points) by 4 gives the half-power beamwidth in degrees (2θ). Turning the antenna on its side and repeating will measure the beamwidth in the other plane. If the antenna does not give more than 3 db. of sun noise, you will have to use a signal generator, and rotate the antenna to measure these beamwidths.

Knowing the beamwidth and the feed-line loss, one can measure the receiver noise figure (assuming a value for T_s). This can be compared with the noise figure measured by using a noise generator. If by measuring solar temperature, using the values you think are correct for your system, you come close to the values shown in Table 1, then you can be sure that your system is performing properly. By measuring these things daily, you can check the performance of your total system.

Summary

In the preceding sections, we have discussed how to measure receiving system parameters, and how to monitor system performance to guard against deterioration. Should you suddenly get 1 db. of solar noise, when you have been getting 3 db., you know that your system needs some checking. Finally, we discussed some of the reasons why this is not an exact measurement, but rather should be taken as an indicator of system performance. QST

[3] Allen, "The Variation of Decimetre-Wave Radiation with Solar Activity," *Monthly Notices of the Royal Astronomical Society*, p. 174 (1957).

Antenna Patterns from the Sun

Using Solar Noise for Plotting Vertical Patterns of V.H.F. Arrays

BY D. W. BRAY,* K2LMG AND P. H. KIRCHNER,* W2YBP

Your v.h.f. antenna is probably aimed at the horizon, but that's not where your signal is going. The radiation in the vertical plane is actually pointed up in the air. This is true whether your antenna is horizontal, vertical or circularly polarized. It occurs because half of the antenna is looking at the ground when it is directed at the horizon. Since the beam strikes the ground, energy bounces off the earth and combines with the energy that is headed skyward.

For a horizontally polarized antenna, which most v.h.f. men use, the reflection is such that the signal is cancelled at the horizon and a sharp beam is formed a few degrees above the horizon. Above this lobe many other weaker and higher-angle lobes are formed. A typical vertical antenna pattern for an antenna a few wavelengths above the ground is illustrated in Fig. 1. A vertically

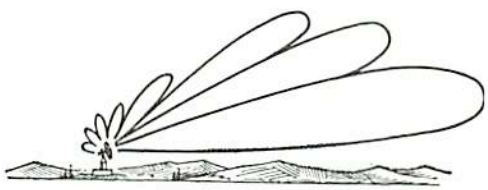

Fig. 1—No antenna ever has a single lobe, aimed precisely at the horizon. As shown in this artist's conception, the main lobe is always at least a few degrees above the horizontal, and other lobes appear above it at higher angles.

polarized antenna would, if the ground were a perfect conductor, add the reflected and direct signal to produce a lobe with its maximum right on the horizon. But the ground isn't a perfect reflector and it causes the same effect as in the horizontal antenna: a lobe structure that is pointing upward.

The only way to beat this is to raise your antenna up as high from the ground as practical to make the first vertical lobe as low as possible. Even though your antenna is as high as you could put it, it still poses the question: is it really high enough; what would another ten feet in elevation buy? Or another question can come to mind as it did at K2LMG. Is that h.f. array, which is below the v.h.f. beam, acting as a ground plane for the latter, causing a high angle of radiation?

The way to answer such questions is to make a vertical antenna pattern plot. That sounds easy but it can't be done as simply as taking a horizontal radiation pattern. To plot a horizontal pattern all you have to do is to have a nearby friend turn on his transmitter, rotate your antenna, and read his signal strength on your S meter.

Although not so easy as the horizontal pattern, the vertical pattern can be plotted by taking a clue from the radio astronomers. Mother Nature has provided a strong and fairly constant source of radio energy a long way off: the sun. In the course of an afternoon the sun sweeps through a range of elevation angles as the earth turns. If you track the sun in azimuth, you can measure the noise level received by your v.h.f. converter as the sun moves down the vertical plane of your antenna. Using the level of the received signal and the calculated position of the sun, the antenna pattern can be plotted.

By this method the question of the h.f. beam at K2LMG was answered. It showed that there was no interaction. If we have excited your curiosity to the point where you would like to run through this experiment for your own antenna, the method is outlined below.

Solar Noise

Since the signal to be received is wide-band noise, the receiver should be opened up to the widest possible bandwidth, so that the greatest amount of noise energy will be collected. But, since this energy is noise a special detector-integrator voltmeter circuit should be used on the output of the receiver in order to smooth out the variations in the noise for more accurate voltage readings. The receiver should be operated with the b.f.o. set for normal c.w. reception. Connect one of the detector-integrators of Fig. 2 to the audio output. One is for use with a volt-ohmmeter, where R = (lowest full scale voltage) × (voltmeter ohms per volt) and $C = \frac{10^6}{R}$ μf., with at least a 6-volt rating. The other is for use with a vacuum-tube voltmeter. If the v.o.m. is used the detector must be connected to the high-impedance tap (the higher impedance the better) of the receiver audio output transformer. It doesn't matter which audio output is used for the v.t.v.m. circuit. Even a high-impedance headphone circuit can be used. The received signals will be read on the voltmeter.

Since the gain of even the very best of receivers will change with time, the effects of

* Advanced Electronics Center, General Electric Company, Ithaca, N. Y.

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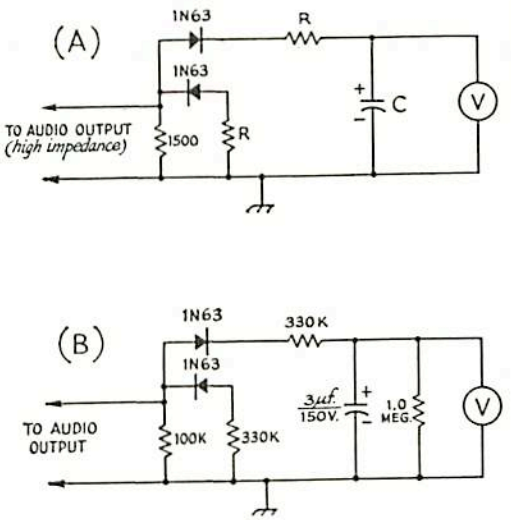

Fig. 2—Detector-integrator circuits for use in taking noise readings. Circuit A is for volt-ohmmeters, B for vacuum-tube voltmeters. See text for information on R and C values in circuit A.

receiver gain variations can be removed by putting a resistor equal to the impedance of the transmission line on a coax connector and substituting it for the antenna and transmission line at the converter input just before each reading is taken. Noise from the resistor provides a "standard signal."

Taking Data

Data can be taken at either sunset or sunrise. By the method outlined in the following section a graph of the angle to the sun as a function of time should be plotted for the selected day previous to taking data. This graph will then give the beginning and ending times of the test. For a sunset measurement, start at the time of maximum desired elevation angle and continue taking readings until about ten minutes after sunset. For a sunrise measurement you should start about ten minutes before sunrise and continue until the time for the maximum desired elevation is reached.

During the run the horizontal position of the sun will change, so it must be tracked in azimuth. Since your beam is relatively broad in azimuth, probably only a few changes in the horizontal position will have to be made.

The readings should be taken every few minutes, and about once a minute at low elevation angles. Each reading should include the time, the voltage output of the receiver with the resistor substituted for the antenna, and the voltage output with the antenna connected. Set the receiver gain so that the voltmeter is about two-thirds full scale on the most sensitive d.c. scale. At times the sun noise will flare up, or a car will go by the house, so caution should be observed to be sure that the reading of the antenna signal is really a good average value. The reading of the sun won't be much larger than that of the resistor and in fact at times will be lower than the resistor, so don't be alarmed by only small changes of voltage. Since the changes are small, care should be taken to achieve accurate results.

Calculating the Sun's Elevation Angle

The apparent motion of the sun is fairly complicated, and you will have to be prepared to do some work here. If you are interested only in the elevation angles below 15 degrees, and are willing to settle for about 1-degree accuracy, the job isn't too bad. The first step is to find your latitude and longitude from a map, and select a date for making the measurements. From Table I, look up the sun's latitude on the selected date, interpolating between tabulated dates.

Second, find out what time the sun will set (or rise) on the chosen day. If you live in a large city you can simply consult a local newspaper or the TV weatherman. The authors have found that in smaller cities these sources sometimes quote times which actually apply to a larger city nearby, and are not accurate enough for our purposes. The same applies if you live more than 15 miles out in the suburbs. In this case, find the correct time from one of the references listed at the end of this article, following the instructions given with the tables.

Next, calculate the number A from the following formula:

$$A = \sqrt{\cos^2 L - \sin^2 D}$$

where L is your latitude and D (declination) is the sun's latitude.

Now, for any time which is M minutes before sunset (or after sunrise), the sun's elevation angle in degrees is equal to A times M divided by 4, or

$$\phi^\circ = \frac{A}{4} M$$

To extend your pattern to elevation angles higher than 15 degrees you will have to work a little harder. In addition to finding the number A, find another number B from this formula:

$$B = \sin D \sin L$$

where D and L are as before. Remember that

TABLE I
Sun's Latitude Variations

Date	Sun's Latitude	Date	Sun's Latitude
Jan. 1	−23.0	July 4	23.0
9	−22.0	12	22.0
21	−20.0	24	20.0
29	−18.0	Aug. 1	18.0
Feb. 8	−15.0	12	15.0
22	−10.0	27	10.0
Mar. 8	− 5.0	Sept. 10	5.0
20	0.0	23	0.0
Apr. 3	5.0	Oct. 6	− 5.0
16	10.0	20	−10.0
May 1	15.0	Nov. 3	−15.0
12	18.0	14	−18.0
21	20.0	21	−20.0
June 1	22.0	Dec. 2	−22.0
10	23.0	11	−23.0
22	23.4	21	−23.4

when D is negative, sin D is also negative.

For a time M minutes before sunset (or after sunrise) find an angle X degrees by dividing M by 4. That is,

$$X^\circ = \frac{M}{4}$$

Now find the elevation angle ø from the equation

$$\sin \text{ø} = A \sin X + B\,(1 - \cos X)$$

The procedure described above gives the elevation angle of the sun at any time it is above your horizon, to about 1 degree accuracy. To get a better picture of the fine structure of your antenna pattern, especially at the low angles which are most important, better accuracy is needed. About 0.2 degree can be achieved by careful calculation and by applying certain corrections.

Read your latitude and longitude to 0.1 degree or better, and find the sunset (or sunrise) time to the nearest minute. Now adjust this time slightly by $\frac{3.3}{A}$ minutes. Add this to the sunrise time, or subtract it from the sunset time. Use this adjusted time to calculate the elevation angles as described above, and then apply a final correction by adding the amount shown in Fig. 3 to the calculated values. These corrections take

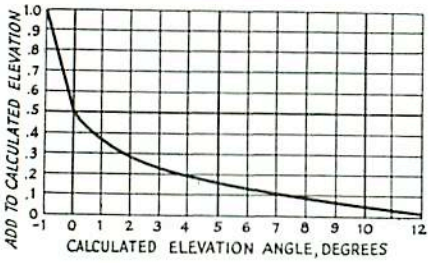

Fig. 3—Chart showing elevation angle corrections to be applied for results of high accuracy.

into account the refraction of the signal (and the light) by the atmosphere, and the difference in size between the radio sun and the visible sun.

Finding the Sun's Azimuth

If you do the job on a sunny day, the simplest way is to have a friend keep the beam pointed toward the sun in azimuth, lining it up by eye. Alternately, calculate the sun's azimuth in advance and rotate the antenna from time to time as required. When readings are taken, the beam should be within about one-fifth of a beamwidth of the sun's azimuth.

Azimuth is found from the formula

$$\cos \Theta = \frac{\sin D - \sin L \sin \text{ø}}{\cos L \cos \text{ø}}$$

ø is the elevation angle already calculated. Again, remember that when D is negative, sin D is also negative. The azimuth, Θ, is measured eastward from north in the morning, and westward from north in the afternoon. When cos Θ comes out negative, Θ is larger than 90 degrees and the sun is more south than north.

Plotting the Results

Now that the angle of the sun and the signal-strength readings have been obtained, the antenna pattern can be plotted. Fig. 4 is a curved-earth grid with elevation angles plotted on it. Taking the readings that were made as the sun ran its course, divide the signal voltage from the sun (E_S) by the signal voltage from the resistor (E_R). Do this for each reading taken. Now square each of these values of (E_S/E_R) to obtain the value of $(E_S/E_R)^2$. The next step is to compute the value Y, using the equation

$$Y = \sqrt{\frac{\left(\frac{E_S}{E_R}\right)^2}{\left(\frac{E_S}{E_R}\right)^2_{\min}} - 1}$$

where $(E_S/E_R)^2$ is each of the readings that were taken as the sun crossed your antenna and $(E_S/E_R)^2_{\min}$ is the value of the reading after the sun is below the zero-degree elevation angle by 5 minutes or more. Then find the greatest value of Y. At this reading, calling it Y_{max}, assign an arbitrary value of slant range — 500 miles. This is then one point on the plot: 500 miles and the angle to the sun at that time. Now take 500 miles and divide it by Y_{max} and multiply all of the other Y values by this amount. Plot on Fig. 4 the angle for each signal-strength reading and distance just found. Drawing the curve, you now have your antenna pattern in the vertical plane.

There is one caution. The sun is not really a point source of radio waves. It can be represented as a ring of about 1-degree angular diameter on the outside and about one-half degree on the inside. Because of this, the nulls in the antenna pattern will not appear to be sharp. For this reason, a sample antenna pattern is shown in order to guide you in your plot. When the curve shows a dip, it probably is a very deep null as indicated by the dotted lines on the same curve, Fig. 5. Because the depth of the nulls cannot be determined, the antenna pattern taken by this method would probably not satisfy an exacting scientist, but in practice the signals that are received on such an antenna, amateur or otherwise, are not from point sources either. Thus the antenna pattern taken by this method is truly an operational pattern.

For those interested in meteor scatter an estimate of optimum range can be made. The meteor trails will be most prevalent at a height of 50 miles. From your antenna pattern note the range at which the elevation angle line through the peak of your lowest lobe intercepts the 50-mile height. Multiplying this number by 2 will yield your approximate optimum meteor scatter range. In the example shown in Fig. 5, this would be about 1000 miles.

Noise Figure and Antenna Gain Check

There is another interesting sidelight to this

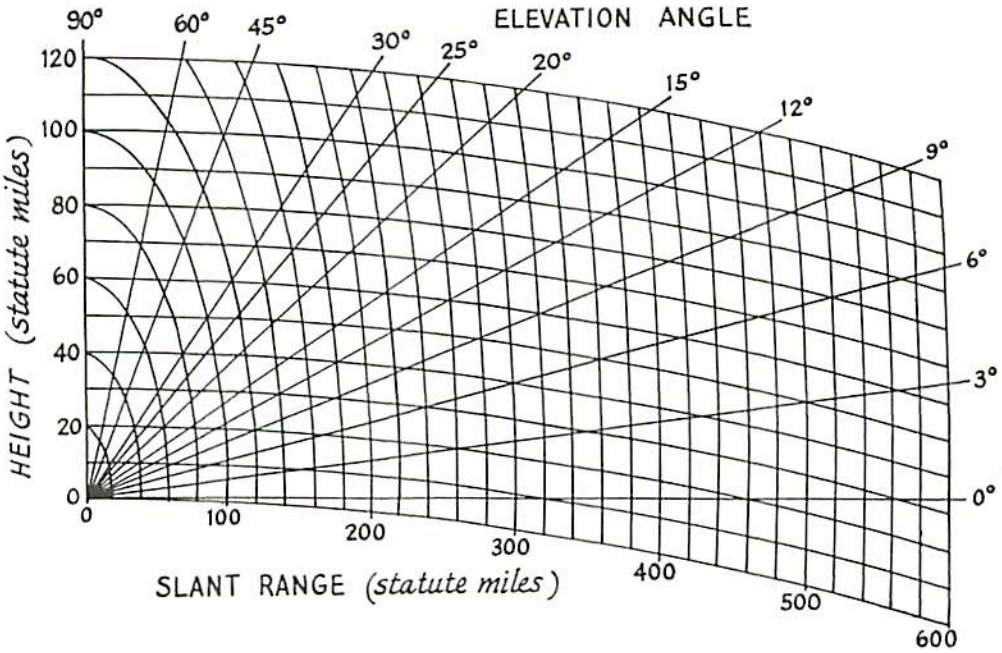

Fig. 4—Curved-earth grid for plotting results obtained from solar noise readings.

subject. The "quiet" sun is a more or less calibrated source of radio energy. Thus by a few simple calculations you can get an idea of your antenna gain or noise figure for actual received signals. Because the amount of energy that is received is a function of both the noise figure and antenna gain, you can start with one of the known values and find the other. The equation which applies is

$$\frac{G_P}{F_P} = 290\,\frac{L_P}{K}\left[\left(\frac{E_S}{E_R}\right)^2_{max} - \left(\frac{E_S}{E_R}\right)^2_{min}\right]$$

where G_P = the power gain on your antenna
F_P = the noise figure expressed as a power ratio
L_P = the transmission line loss for your cable and your length
K = a constant dependent upon the frequency band

and

$$\left(\frac{E_S}{E_R}\right)^2_{max}$$

is the maximum signal ratio from the antenna pattern data taken above. This value will occur at the peak of the first vertical lobe. $(E_S/E_R)^2$ min is the signal ratio at the time the sun was a few minutes below the horizon.

This formula will only apply when the sun is quiet. If the answers are out of line the test should be repeated until a quiet day is found. A quiet sun radiates the lowest amount of energy; all other conditions produce greater received power.

Your antenna gain is probably the least well-known number of your radio system.

TABLE II

Frequency Band	*Value of K*
144 Mc.	2.9
220 Mc.	2.8
432 Mc	2.7
1296 Mc	0.65

To calculate the antenna gain:

1) Estimate the noise figure of your converter by taking the manufacturer's noise figure, or from tube data if it is a home-brew model. This value will probably be expressed in db. Convert the db. noise figure to a power ratio by the common db. formula, F_P = antilog $F/10$ where F is the noise figure in db. from above. This conversion can also be made using the decibel chart in the *ARRL Handbook*.

2) The factor K is listed in Table II for the various amateur bands above 50 Mc. The 6-meter band has been omitted because of the strong background of radio energy in this frequency range in large areas of the sky, which could adversely influence the results. For the higher bands the background radiation is much less. It is possible that one of the bright radio stars could be near the sun when the measurement is being taken, and would therefore influence the readings on the higher frequencies, also, but the chances of this are remote.

3) L is the line loss. This figure is easily estimated by looking up the transmission-line manufacturer's data for your frequency. It is usually expressed in db. loss per hundred feet. Thus, calculate the db. value for your length and convert the db. loss to a power ratio as you did above for the noise figure.

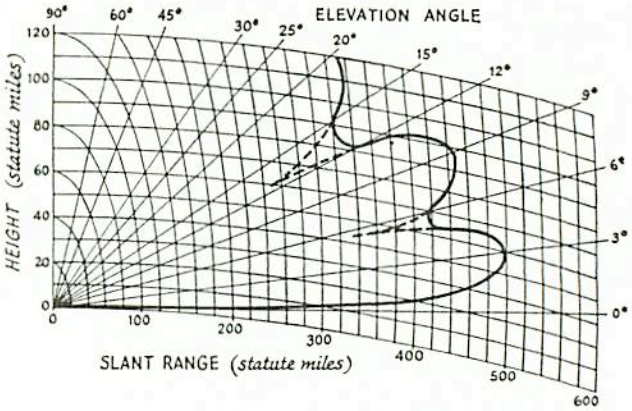

Fig. 5—Representative vertical antenna pattern. Dips in the heavy line represent nulls in the pattern which are actually much deeper than data will indicate. This is due in part to the fact that the sun is not a true point source for radio noise. Antenna pattern may be more like that shown in dotted lines.

Substitution of the values in the formula will yield the power gain G_P of the antenna. This can be converted to db. gain by the common formula

$$G = 10 \log G_P,$$

or by using the *Handbook* table.

What we have really been talking about here is a practical use of radio astronomy. The methods used here also apply to the detection of radio stars. Many interesting experiments can be performed. For those who are interested, take a radio look at Cygnus A or the center of our galaxy in Sagittarius, when they are rising or setting. Both are good strong noise sources, and real DX! QST

References

American Ephemeris and Nautical Almanac, issued yearly by U. S. Naval Observatory. Consult it at library.

Astronomical Phenomena for the Year, published annually. A reprint of selected pages from the above, 25 cents from Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.

The Telephone Almanac, issued annually. Free from Bell System Telephone Company business offices.

Information Please Almanac, published by Macmillan Company, New York City; sold at newsstands and bookstores

MORE 50-MC. MOONBOUNCE EXPERIMENTS

Aylmer
Quebec
Canada

Technical Editor, *QST*:

The purpose of this letter is to give corrections and additions to a previous one,[1] and to describe further 50-Mc. moonbounce experiments at VE3BZS/2.

In the formula for the Doppler shift, the transmitter frequency, f, should have been expressed in cycles, not megacycles. Also, it was mentioned that the antenna was usually aimed optically. However, the following formulae were referred to when the moon was obscured by clouds:

$$\sin E_T = \sin L_T \sin D + \cos L_T \cos D \sin H_T$$

$$\sin A_T = \frac{\cos D \cos H_T}{\cos E_T}$$

where E_T is the elevation of the transmitting antenna
A_T is the azimuth from true north
L_T is the latitude of the transmitter
H_T is the hour angle of the moon, and is approximately

$\frac{360}{(transit)} \times t$, where t is the time in hours after local mean time of moonrise at the equator, and (*transit*) is the time in hours between ephemeris transits of the moon (approx. 25 hours).

Similarly for the receiver.

The formulae are approximations, since E_T is the elevation of the moon at the earth's center, not at the station. However, the difference is less than one degree, at most. Also, the local hour angle definition may not be standard.

The moonbounce experiments were continued with different antenna polarizations to see if improvement could be obtained. It was pointed out by Soifer[2] that crossed Yagi antennas transmit and receive the same sense of elliptically-polarized radiation. Thus, theoretically, assuming specular reflection of the radio wave at the moon's surface and therefore reversal of the sense of the polarization, the antenna used in the experiments previously described should not have received the transmitted echoes. Neglecting effects of the ionosphere and lunar surface, the fact that some echoes were received is probably attributable to ground reflection effects and/or transmission of elliptically-polarized waves due to mismatch in the antenna system.

[1] "50-Mc. Moonbounce Experiments," Technical Correspondence, *QST*, May, 1962, p. 49.

[2] Soifer, "Research, Tracking and Reporting, Project Echo A-12," *QST*, June, 1962.

A trial was made recently using two of the crossed Yagis transmitting radiation polarized in one sense and the other two receiving in the opposite sense. Stronger and more frequent echoes were recorded, even though the system gain (neglecting the problem of reverse polarization) was only one-fourth that previously used.

Another trial was then made with the four antenna units transmitting vertically. This was chosen over horizontal to have the major lobes of the upper and lower bays as nearly coincident as possible, in the event of ground reflection. During this trial the moon was obscured, and some power-line interference was present, but results were the best so far.

The 50-Mc. trials were brief and incomplete, but results seem to indicate that the echo amplitude varies widely; that the average signal-to-noise ratio of the echoes is less than that given by the formula in the previous letter; that, when using circular polarization, improved performance results if the transmitting and receiving antennas have opposite polarizations; and that, with the system parameters used, no distinct advantage between circular and linear polarization was noticed.

— *Alan Goodacre, VE3BZS/2*

SUN NOISE

Technical Editor, *QST*:

Some questions have arisen over the definitions used in the article on sun noise (April 1968 *QST*, page 42), and perhaps a note clarifying these is in order. To conform to common usage, as stated in the *IEEE Standards*, the relation between noise figure and noise factor should be:

Noise Figure = 10 log (Noise Factor).

Thus, ". . . add 1 . . ." is incorrect, and a noise figure of 6 db. corresponds to a noise factor of 4. Also, as used in the equations, A is the fractional transmission of the feed line, rather than its fractional loss. Fractional transmission equals one minus fractional loss, resulting in A being correctly given in the example. However, the redefinition of N, as above, changes the results of the example so that the sun noise, taking one linearly-polarized component, should be 4.8 db. above the receiver noise, for the other constants assumed in the example.

One last word of caution: the whole presentation was based on the ratio signal/noise rather than signal + noise/noise. For systems where the sun is only slightly above the noise, reduction to signal/noise ratio, as described in January 1968 *QST*, page 34, may be required. — *Don Lund, WAØIQN, P.O. Box 1664, Boulder, Colorado 80301.* QST

50-MC. MOONBOUNCE EXPERIMENTS

119 Fourth Ave.
Ottawa
Ontario, Canada

Technical Editor, *QST:*

Communication by moon-reflected radio waves offers amateurs the opportunity for making v.h.f. contacts anywhere in the world, for periods of from a few minutes to several hours each day, if the considerable technical problems can be solved. The following describes some attempts to obtain moon echoes on 50 Mc.

Previous work with the reception of 50-Mc. transmissions by W7RDY at VE7AIZ gave evidence of perhaps two or three consecutive weak echoes during each of half a dozen trials.[1] Lack of more consistent results was assumed to have been due to Faraday rotation of the plane of polarization in the ionosphere, causing loss of signal. Antennas at both ends were horizontally-polarized Yagis. It seemed worth while to make another attempt at VE3BZS, using circular polarization, in a manner similar to that used by K1HMU [2] to overcome the Faraday-effect problem.

Four Yagis, each with 5 elements in a horizontal plane and 5 in a vertical plane, were arranged in box configuration approximately 20 feet square. The vertical driven elements were fed 90 degrees out of phase with the horizontal ones. The antenna could be rotated only in azimuth, and was usually optically aimed. The transmitter used a heterodyne exciter for maximum stability. An external tunable oscillator at 1 Mc., with 50 times frequency multiplication, gave receiver injection at 50 Mc., plus the Doppler shift, plus or minus the audio filter frequency of 940 cycles. This beating signal and the returned signal, if any, are fed into the regular 50-Mc. converter, and then into the station receiver, set for 600-cycle bandwidth. Then follows the 940-cycle audio filter, with a bandwidth of 20 cycles, and a tape recorder.

An important receiver point is that the gain of the receiver should be set so that the noise at the output of the audio filter disappears when the external injection is turned off. Under this condition the effective predetection (i.f.) bandwidth of the receiving system is determined by the audio filter. The heterodyne system for the transmitter allows the oscillators to run continuously, permitting better frequency stability than when turning the oscillator on and off. Heterodyning also reduces the drift at the signal frequency, for a given amount of oscillator drift, compared to a conventional oscillator-multiplier system. Absolute frequency stability was not extremely good, due to lack of temperature control of crystals and transistors, but relative drift to the receiver was from one to two cycles per minute. This is good enough to permit audio filter selectivity of 10 to 20 cycles to be used.

Because of this narrow bandwidth the Doppler shift had to be calculated. The approximate formula used was:

$$\Delta f = f\left[\frac{37.04}{(\text{transit})}(\cos L_T \cos H_T + \cos L_R \cos H_R)\cos D \times 10^{-6} + 5.54\left(\frac{1}{(\text{semi})_1} - \frac{1}{(\text{semi})_2}\right)\times 10^{-2}\right]$$

where Δf = Doppler shift in cycles;
f is = transmitter frequency in megacycles
$(\text{semi})_1$ = semidiameter of the moon expressed in seconds of arc
$(\text{semi})_2$ = semidiameter of the moon expressed in seconds of arc 12 hours later for the day concerned
(transit) = the time in hours between ephemeris transits of the moon (approx. 25 hours)
L_T = latitude of the transmitter
H_T = hour angle of the moon and is approximately $\frac{360}{(\text{transit})} \times t$ where t = time in hours after local mean time of moonrise at the equator
L_R, H_R similarly for the receiver
D = apparent declination of the moon

[1] *The VHF Amateur*, February, 1961, pp. 13–16.
[2] See photos in *QST*, November, 1961, p. 89.

The necessary information for the calculation may be obtained from a current *American Ephemeris and Nautical Almanac*. The first term in the square brackets is usually dominant and at moonset at 45 degrees latitude amounts to about − 110 cycles at 50 Mc.

Three trials were made and only one or two weak but identifiable echoes were received. Signal-to-noise power ratios were of the order of 1:1, or less. This means that little or nothing can be heard of the return signal by ear, but a visual presentation shows evidence of a return. The advantage of visual methods in detection of very weak signals increases with very narrow receiver bandwidth, since signal and noise tend to sound the same under these conditions.

The average signal-to-noise ratio at the output of the audio filter was calculated using the following formula, which neglects fading effects produced by the motion of the moon's surface, Faraday rotation and ground reflection:

$$\left(\frac{S}{N}\right)_{\text{POWER}} = \frac{1.6 \times 10^{-26}\, G_R \lambda^2\, G_T P_T\, 10^{\frac{-2KL}{10}}}{4.1 \times 10^{-21}\left(.22\lambda^{2.4}\ 10^{\frac{-KL}{10}} + F - 1\right) B}$$

where P_T = transmitter power output in watts
K = attenuation of transmission line in db./100 ft.
L = transmission line length in units of 100 ft.
λ = wavelength in meters
G_R = gain of receiver antenna over isotropic radiator
G_T = similarly for transmitter
F = noise figure of receiver at wavelength λ
B = effective noise bandwidth of receiver in c.p.s.

It should be noted that P_T, K, and F vary with λ for given components. Frequency stability problems make minimum B vary with λ also. For given conditions there is an optimum λ to produce maximum average signal-to-noise ratio. The words "average signal-to-noise ratio" are used, since the instantaneous noise power may deviate from the average value, but the actual signal-to-noise ratio should be within a factor of two of the average about 50 per cent of the time.

The calculated signal-to-noise power ratio using:
P_T — 400 watts
K = 3 db./100 ft.
l = 100 ft.
λ = 6 meters
G_R = 64
G_T = 64
F = 2
B = 20

gives $\left(\frac{S}{N}\right)$ = 1:1.

A possible explanation for lack of consistent (although weak) echoes may be that the image antenna produced by ground reflection (assumed perfect for sake of argument) is causing cancellation and reinforcement [3] of the circularly polarized radiation in such a manner that alternate zones of radiation are produced where the polarization changes from being completely vertical to being completely horizontal. When the moon is in a zone where the radiation is predominantly linearly polarized, Faraday rotation may cause loss of signal, when transmitting with circular polarization.

A comparative test between VE3BZS/2 and another local station, with distant stations using horizontally polarized antennas, gave signals several db. lower than expected. Probably this was due, in part at least, to ground reflection producing predominantly vertically polarized radiation at low angles, when using circular polarization at VE3BZS/2.

The results of these 50-Mc. tests seem to show that 50 Mc. is not too practical under present conditions for amateur moonbounce work. Also circularly polarized antennas may suffer a loss in efficiency under conditions of good ground reflection in combating Faraday-rotation effects.

The narrow-band methods used in the receiver and transmitter should be adaptable for use on higher frequency amateur bands to allow use of existing equipment with little modification and cost. — *Alan Goodacre, VE3BZS*

[3] *The A.R.R.L. Antenna Book*, pp. 46–48.

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